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REPORT OF SURVEY OF THE TRUCKEE RIVER

R. L. O'Connell, et al

Public Health Service
Washington, D.C.

July 1962

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Title - Report of Survey

of the

TRUCKEE RIVER

by

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Field Operations Section
Technical Services Branch
Division of Water Supply and Pollution Control
Public Health Service
Department of Health, Education, and Welfare

July 1962

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Report of Survey of the

TRUCKEE RIVER

INTRODUCTION

The river survey described in this report was conducted in response to a request from the Nevada State Department of Health for technical assistance in evaluating the self-purification characteristics of the Truckee River below the cities of Reno and Sparks, Nevada. These two adjacent communities presently discharge treated sewage effluents to the Truckee River. The State Department of Health, with the cooperation of these cities, is presently seeking to determine what additions and improvements in waste treatment measures must be adopted in order to protect the quality and usefulness of the Truckee River in future years. In order to accomplish this, much detailed information on the river itself is needed. The primary objective of this survey, therefore, was to obtain information of the type which would be helpful for stream pollution abatement planning purposes.

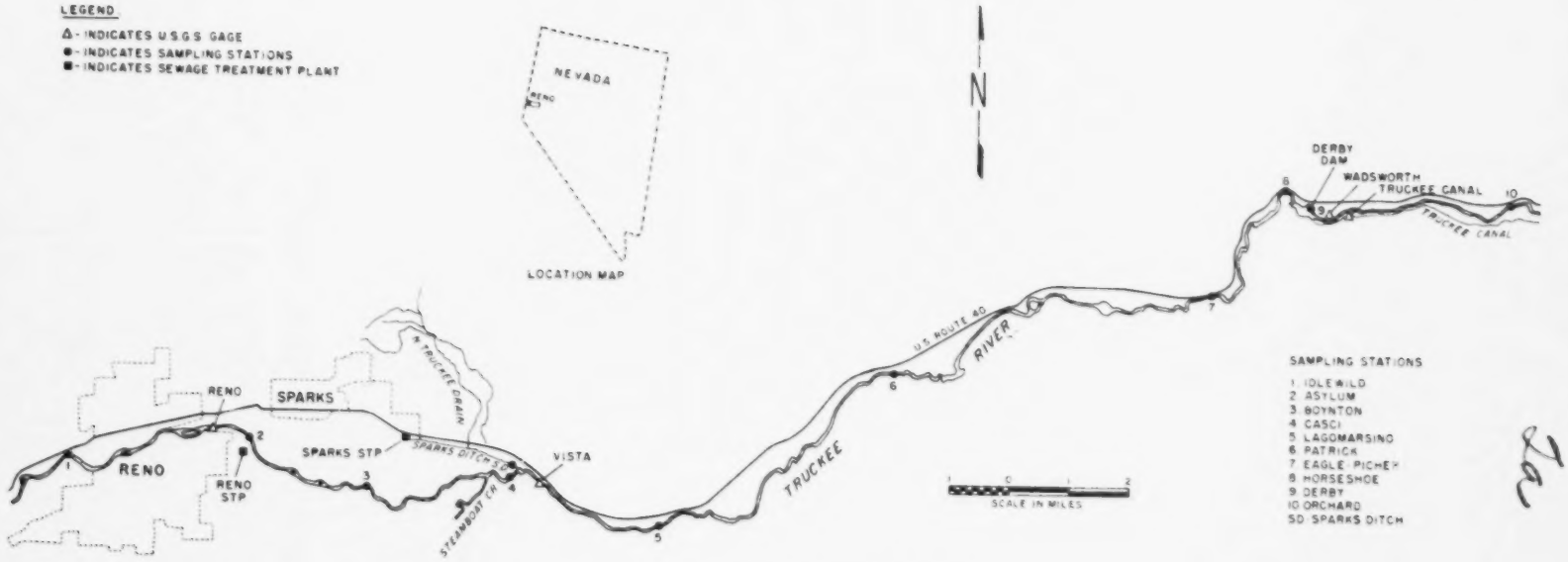
Major interest was expressed by the State in the oxygen resources of the river. The survey was designed, accordingly, to obtain data useful to an analysis of stream oxygen relationships. Because of the potential importance of aquatic organisms to these relationships and to evaluate the effects of present waste discharges on the stream life, a biological investigation was included as an important part of the survey.

HYDROLOGY

The Truckee River originates as the outflow from Lake Tahoe on the California-Nevada border. From the lake elevation of 6228 feet it flows in a general northeasterly direction for 106 miles to its terminus at Pyramid Lake, Nevada, at an elevation of 3880 feet. Several small mountain streams join the Truckee, and numerous diversions take water from it before it reaches the city of Reno. The flow in the Truckee above Reno is regulated at Lake Tahoe, Boca Reservoir, Donner, Independence, and Weber Lakes, and by several power plants. Both above and below Reno the river is used extensively for irrigation. All but a very small flow (20 cfs during July 1962) is diverted through the Truckee Canal from the Derby Dam impoundment, 25 miles below Reno, to the Lahontan Reservoir. Irrigation return waters drain to the Truckee below Reno at two major locations: Steamboat Creek and the North Truckee Drain (see Figure 1).

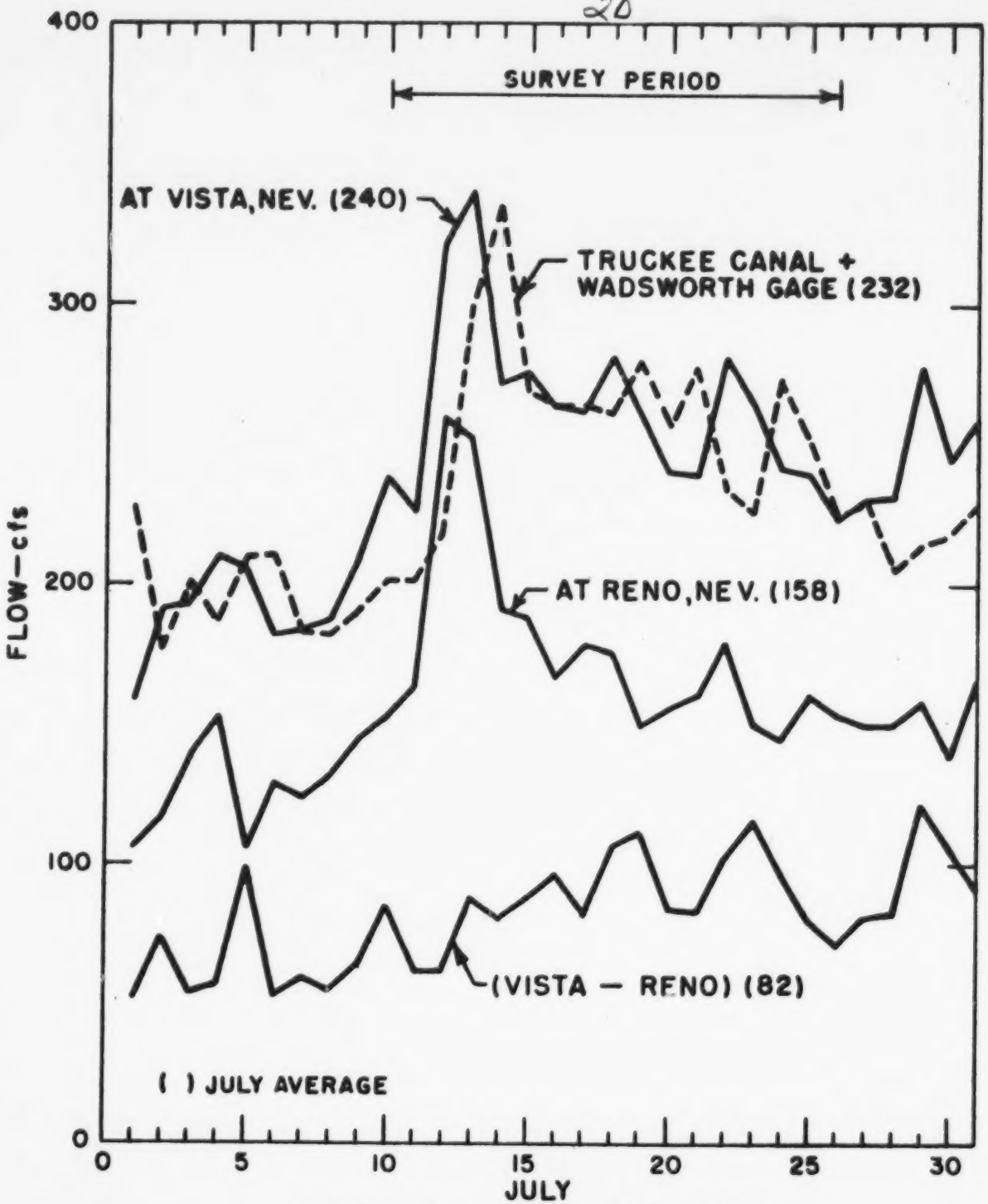
This survey was concerned principally with a 30-mile stretch of the river from Reno to Derby Dam. Four stream gages are maintained in this stretch; three by the U. S. Geological Survey at Reno, Vista, and Wadsworth, and one by the Truckee-Carson Irrigation District on the Truckee Canal. Flow records at these stations during July 1962 are shown in Figure 2. This hydrograph shows the flow at Vista to be significantly higher than that measured at Reno just 6.4 miles upstream. This increase in flow which averaged 82 cfs during July has been accounted for as follows:

Reno Sewage Treatment Plant	15.5 cfs
Steamboat Creek	40
Sparks Sewage Treatment Plant	6.5
North Truckee Drain	20
	82 cfs



TRUCKEE RIVER SURVEY AREA

FIGURE 1



STREAM FLOW - JULY, 1962
TRUCKEE RIVER
FIGURE 2

The flow attributed to Steamboat Creek (40 cfs) is lower than that actually measured on one occasion during July (90 cfs). This may indicate that other significant diversions took place between the Vista and Reno gages, although none were noted during the survey.

It may be noted also from the hydrographs that the combined flow at Wadsworth, just below Derby Dam, and that of the Truckee Canal approximately equal the flow recorded at Vista. If this combined flow is compared to the flow at Vista the previous day they will be found to be almost identical. This procedure is a reasonable one since the time of passage between Vista and Derby Dam, as will be discussed later, is approximately one day. This comparison shows that the minor diversions from the Truckee in this stretch are very nearly balanced by return flows.

The increase in flow at Vista from 226 cfs on the 11th to 3'0 cfs on the 13th was due to the 0.22 inches of rainfall which occurred on the morning of the 12th. Table 1 shows this and other climatological data for the survey period as observed by the U. S. Weather Bureau at their station located at the Reno Municipal Airport. After the 13th the flow at Vista returned to about 250 cfs and remained near that level during the remainder of the month.

The lowest flows in this stretch of the Truckee are normally experienced during July, August, or September. The average monthly flow observed at the Vista and Reno gages during these months is shown in Table 2.

Table 1

Climatological Data

U. S. Weather Bureau, Reno, Nevada, July 1962

Date	Air Temp. °F Min.	Air Temp. °F Max.	Precipitation (inches)	Ave. wind speed (mph)	% of possible sunshine
10	47	86	0	6.7	86
11	45	85	0	6.3	72
12	53	78	0.22	7.0	54
13	49	83	0	6.3	99
14	44	85	0	4.9	100
15	41	86	0	4.3	100
16	40	89	0	4.6	100
17	48	89	0.05	5.3	58
18	43	88	0	7.5	100
19	43	91	0	5.2	89
20	46	93	0	4.8	100
21	45	94	0	5.7	100
22	47	94	0	5.3	88
23	47	95	0	5.2	81
24	53	92	Trace	5.8	72
25	46	92	0	5.3	100

	July 1	July 31
Sunrise	4:35 AM	4:57 AM
Sunset	7:30 PM	7:13 PM

Table 2

Average Monthly Flows (cfs)

Truckee River

Station	July	August	September	October	Period of Record
Vista	328	248	296	361	1932-1960
Reno	413	217	203	211	1906-1935, 1943-1960

The average flows occurring during July 1962, 240 cfs at Vista and 158 cfs at Reno, were somewhat lower than normal for this month.

During the recent eleven-year period from 1950 to 1960 the minimum seven day flow rate at Reno fell below 100 cfs on but one occasion. This was in November 1950 when the flow rate for the first seven days of that month was 81 cfs. The average minimum annual seven-day flow rate during this eleven-year period was 140 cfs. August was the month during which this minimum flow period occurred most frequently, i.e., five times. It occurred in June in three of the years and once each in July, October, and November.

No attempt was made to carry out a low flow frequency analysis on these river stations. Information concerning the details of flow regulations in this stretch of the river, which is necessary for a proper analysis of low flow frequency data, was not readily available at the time this report was prepared. It is understood that the U. S. Geological Survey will carry out such an analysis at their data processing center in Washington, D. C., and these results should be available in the near future.

WASTE SOURCES

The two major waste sources on this stretch of the Truckee are the treated sewage effluents from the cities of Reno and Sparks. Both plants employ high-rate trickling filters followed by clarification as the secondary treatment step. Post chlorination is also practiced at both plants.

The Reno plant serves approximately 58,000 people on a combined storm and sanitary sewerage system. The plant effluent is discharged to the Truckee River at river mile 0.7 through a short ditch. Since Reno has a combined sewerage system, overflows of untreated sewage directly to the stream will occur to some extent during rainstorms.

The Sparks plant serves 22,000 people on a separate sewerage system. This effluent is discharged to a drainage ditch (Sparks Ditch) in which it flows 2.1 miles before entering the Truckee River at river mile 6.0. Irrigation return water from the North Truckee Drain enters Sparks Ditch at 0.9 miles above the mouth of the ditch.

Steamboat Creek enters the Truckee at mile 5.7 or 0.3 miles above the mouth of the Sparks Ditch. This flow drains agricultural lands and is made up partially of irrigation return waters.

DESCRIPTION OF SURVEY

The survey commenced on July 10, 1962, and continued for sixteen days until July 25, 1962. During the first seven days samples were collected from the stream at the eleven locations shown in Figure 1 and described in Table 3. The stream was sampled at approximately six-hour

Table 3

Sampling Stations

Field No.	Description	River miles below Reno gage
1	IDLEWILD - At partial rock dam adjacent to Idlewild Park	-2.8
2	ASYLUM - Glendale St. Bridge just above Reno STP discharge point	0.5
RSTP	RENO Sewage Treatment Plant - Effluent samples taken at Parshall Flume just ahead of discharge to effluent ditch	0.7
3	BOYNTON - Boynton Lane Bridge	2.8
4	CASCI - On Casci Ranch just opposite mouth of Steamboat Creek	5.7
SSTP	SPARKS Sewage Treatment Plant - Effluent samples taken at open concrete box just ahead of discharge to effluent ditch	6.0
SD	SPARKS DITCH - Private vehicular bridge on Casci Ranch 0.2 miles above mouth of ditch	6.0
5	LAGOMARSINO - Vehicular bridge near Lockwood	8.7
6	PATRICK - Private vehicular bridge near Patrick Ranch	14.0
7	EAGLE-PICHER - Bridge on road approaching Eagle-Picher Co. Plant. Highway 40 turn-off at Clark's Station	21.0
8	HORSESHOE - At last railroad bridge above Derby Dam. In impoundment backwater.	23.8
9	DERBY - At upstream face of Derby Dam. Samples at one foot below surface(S) and just off bottom(B) at 10-15 ft. depth	24.2
10	ORCHARD - Private vehicular bridge 0.1 mile off Highway 40	28.0

intervals. The time of collection was varied each day so that the 27 samples collected from each station were uniformly spread over the 24 hours of the day. During this first week samples were also obtained of the treatment plant effluents from the cities of Reno and Sparks. These were collected every two hours by the treatment plant operators and were composited according to the plant flow over each six-hour period of collection. The second week was devoted to special sampling of the stream.

Diurnal dissolved oxygen measurements were made at each station with observations at two-hour intervals over a 24-hour period. Dissolved oxygen stream measurements were also made on an incremental volume of water as it flowed downstream. A dye tracer was used to determine time of passage along the river, and stream cross-sections were obtained at several points.

Laboratory analyses were carried out in a trailer laboratory located at the Sparks sewage treatment plant. Stream samples were analyzed for dissolved oxygen (DO) biochemical oxygen demand (BOD), and temperature. Sewage treatment plant effluent composite samples were analyzed for BOD and grab samples for DO and temperature. All DO and BOD tests were made in duplicate. DO samples were initially fixed in the field but parallel measurements indicated no significant changes if samples were iced in the field and fixed in the laboratory, and this procedure was used for practically the entire survey. The water used for dilutions in the BOD test was obtained from the Truckee River at Farad, California, about 20 miles above the city. With few exceptions it was

possible to conduct BOD tests on stream samples without the necessity for dilutions.

A limited number of additional laboratory tests were performed on samples which were shipped to Cincinnati. These included mineral, nitrogen, and phosphorus analyses. The State Department of Health examined a limited number of samples for coliform bacteria.

TIME OF PASSAGE

Since many of the reactions involving stream pollutants are time dependent, it is most important that reasonably accurate estimates of the time of passage between river stations be made. These times will vary with stream flow rates and it is desirable to be able to predict these changes.

In this survey a relatively new technique was used to measure time of passage. A fluorescent dye tracer was introduced into the river to "tag" a given mass of water. At a downstream station water was continuously pumped from the river through a detection instrument (GK Turner Fluorometer) which measured the amount of dye present to a lower limit of sensitivity of 0.1 parts per billion. The measured dye concentration is continuously recorded, providing a permanent record of the passage of dye at the downstream station. This procedure was carried out for eight different stream stretches from the sampling station farthest upstream to Derby Dam. The information obtained by these tests served to check the reliability of the estimating procedure which is described below. (Detection instrument shown in Figure 3.)

The U. S. Geological Survey provided cross-sections of the river at their Vista and Reno gage stations. This information was used to develop the plots and equations shown in Figure 4. A log-log plot of flow versus mean velocity at these stations can be fitted quite well by a straight line. At ten other downstream locations cross-section measurements were made at the particular flow then occurring. At each of these cross-sections the mean velocity at that flow was calculated and this single point plotted on log-log paper. A straight line was drawn through that point at a slope equal to that of one of the lines shown in Figure 4. For stations below Vista the slope of the Vista curve in Figure 4 was used. For stations between Reno and Vista an average of these two slopes was used. The log-log plots so constructed were then used to predict mean stream velocities at a wide range of flows, and permitted the development of the plot shown in Figure 5. This gives times of passage for the Truckee at five flows from 50 to 250 cfs. At flows much lower than 50 cfs the prediction method used cannot be considered as reliable, but would still probably be adequate for most uses.

Figure 5 may be used to determine the time of passage between any two locations on the river. For example, the time of flow from a point four miles to one eight miles below the Reno gage would be found as follows. If the flow at Mile 4 is 150 cfs, the intersection of the 150 cfs line and Mile 4 on the x axis is used as the starting point. The y axis value is noted to be six hours. The 150 cfs line is followed until Steamboat Creek is reached, where it will be assumed, 50 cfs is added. The y axis value is now 8.2 hours and the time of passage in this stretch is 2.2 hours (8.2-6.0). Following the 200 cfs line from this point to

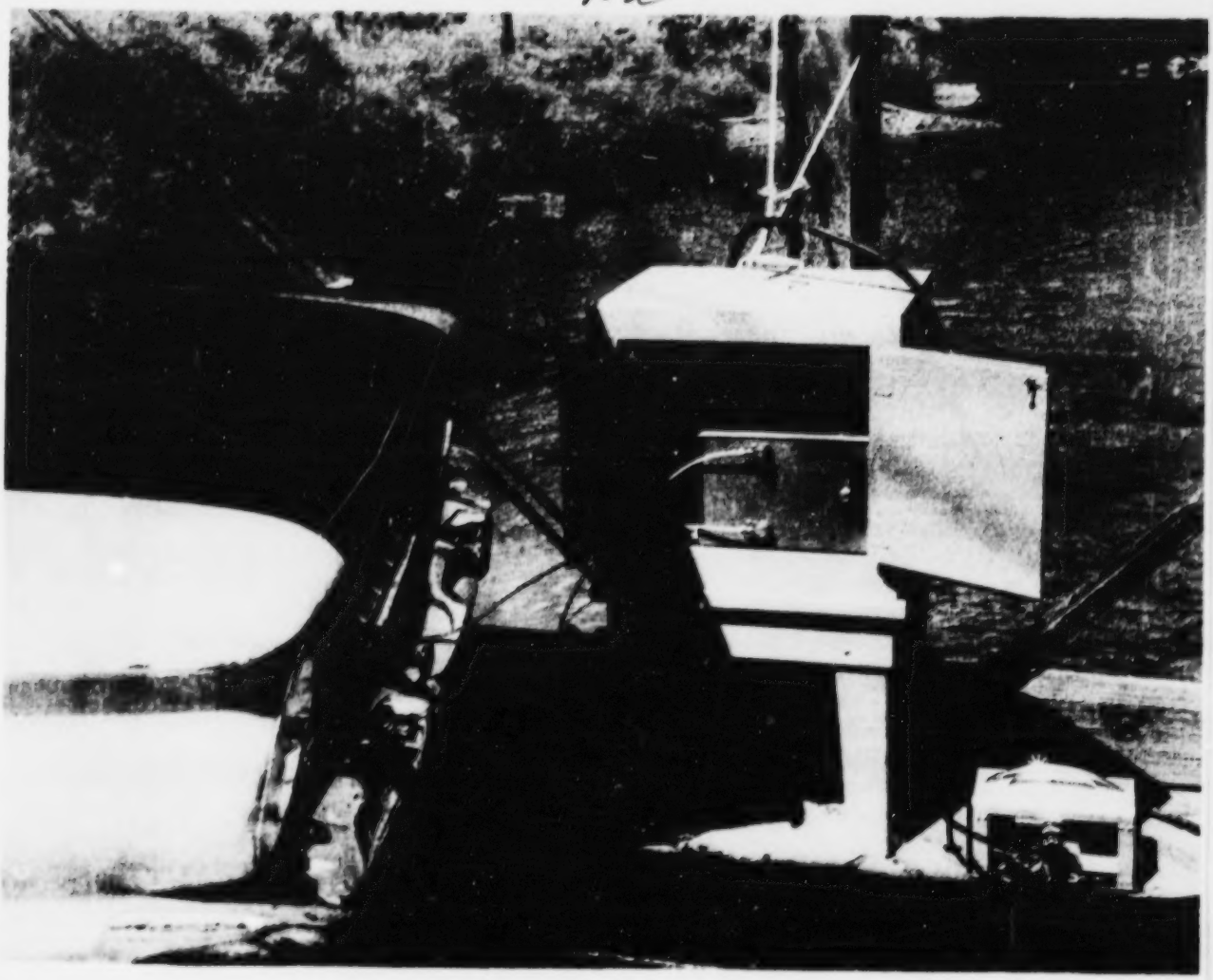
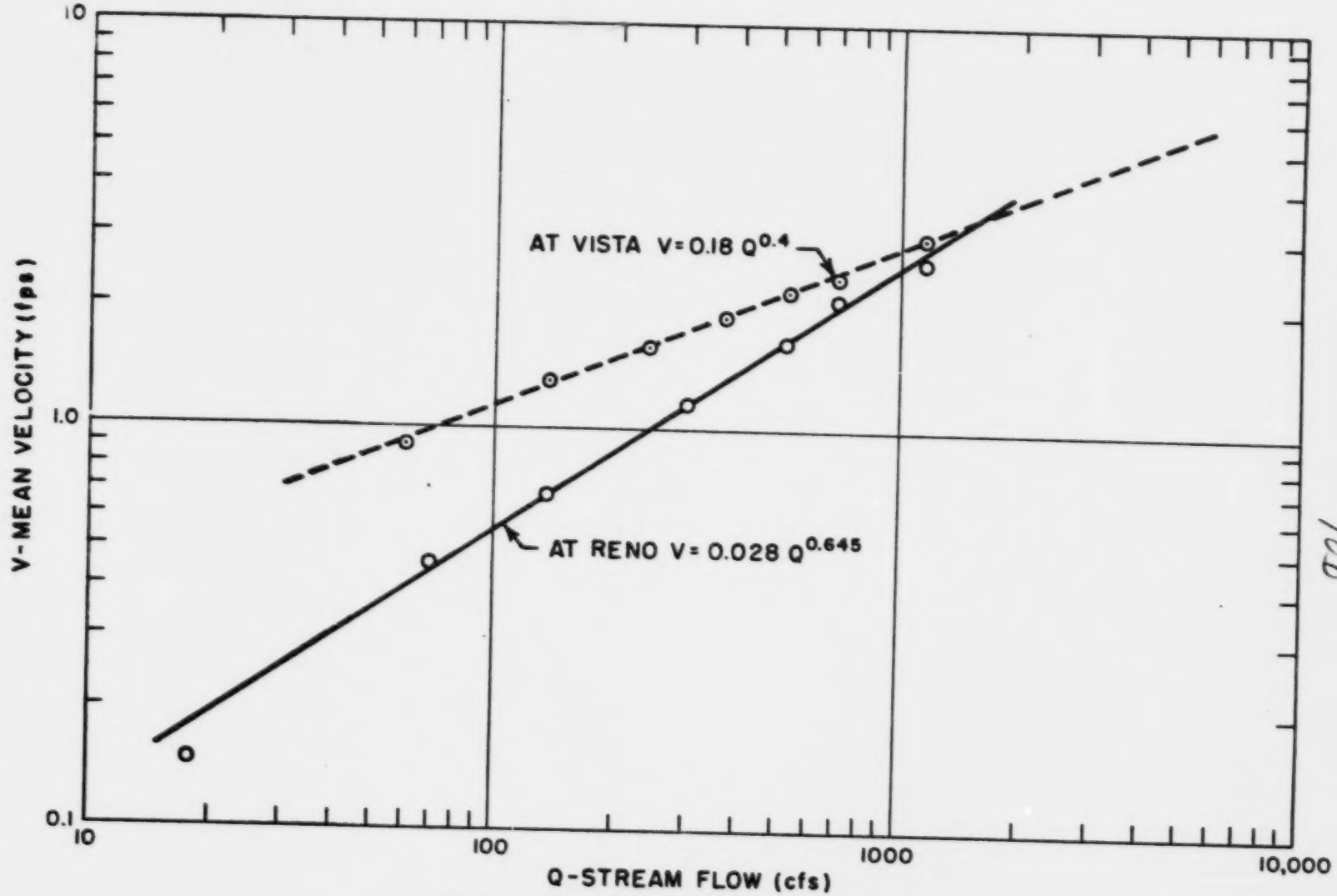


Figure 3

View of fluorometer as set up at a Truckee River sampling station for field measurements. The car's 12-volt power source is passed through converter at lower right to obtain 110 volts needed for the pump, fluorometer, and continuous recorder. The pump, suspended near the water's surface, delivers a continuous sample to the fluorometer.



MEAN VELOCITY VS. STREAM FLOW
TRUCKEE RIVER
FIGURE 4

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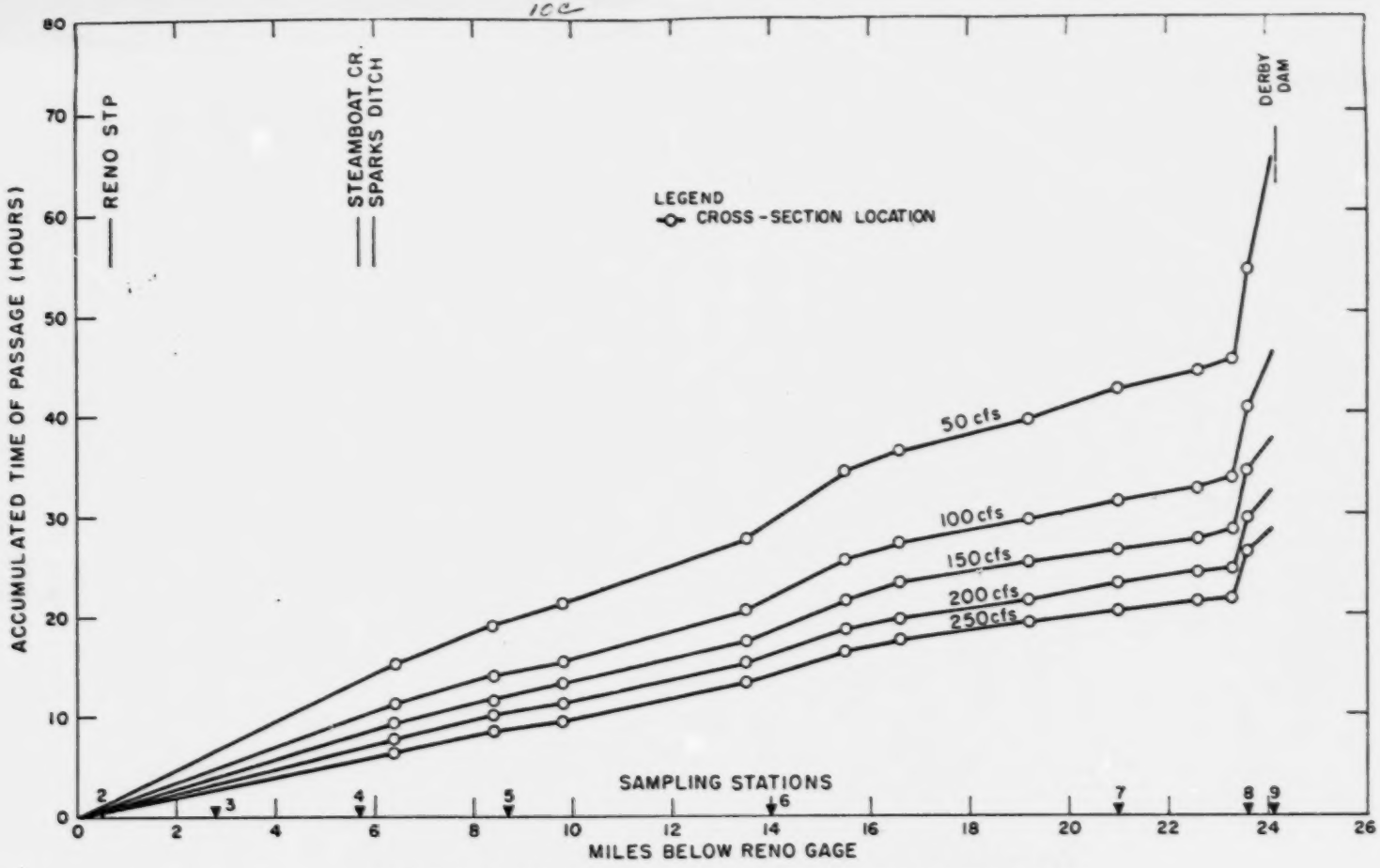
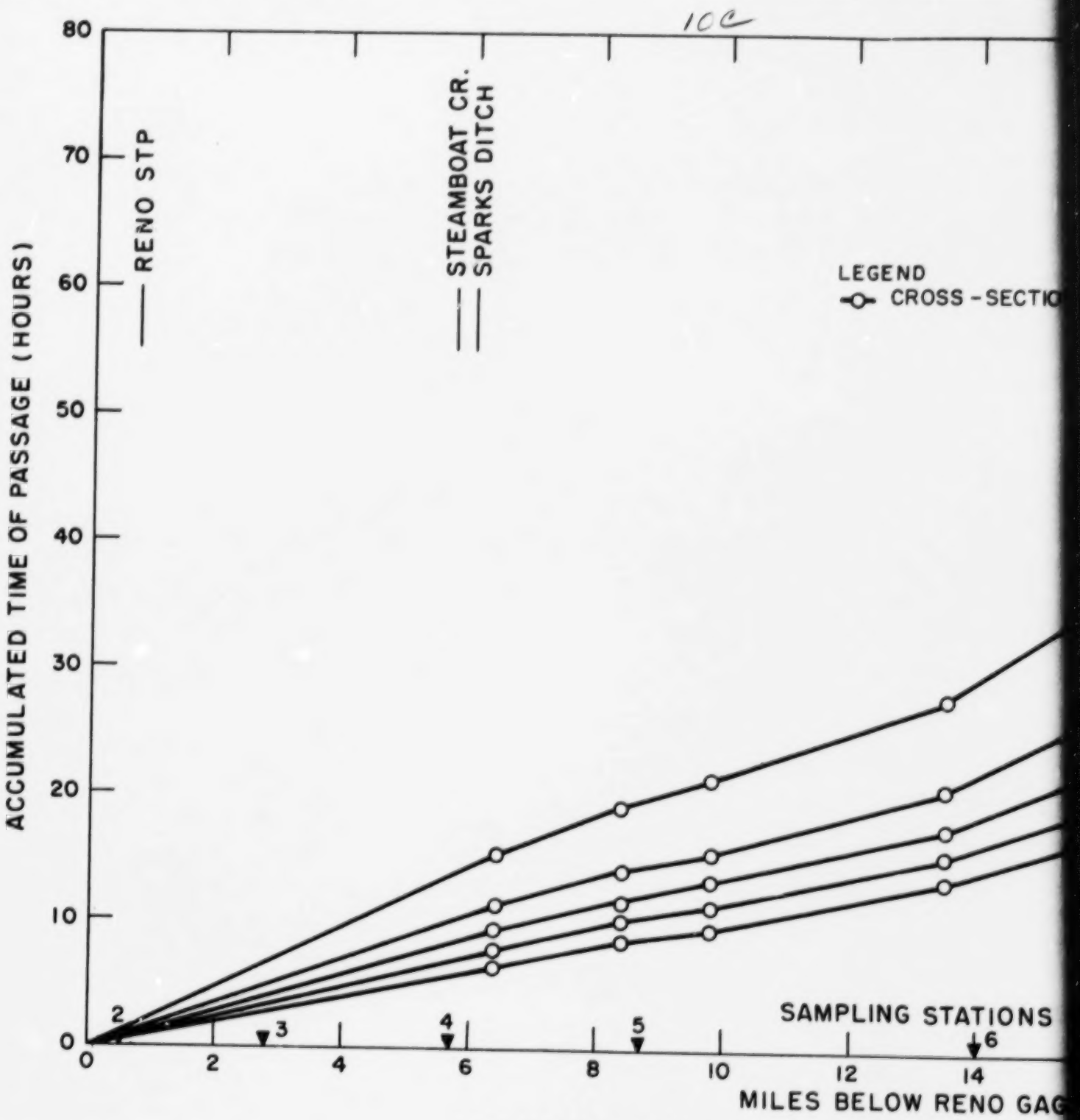


ACCUMULATED TIMES OF PASSAGE AT INDICATED FLOW

TRUCKEE RIVER

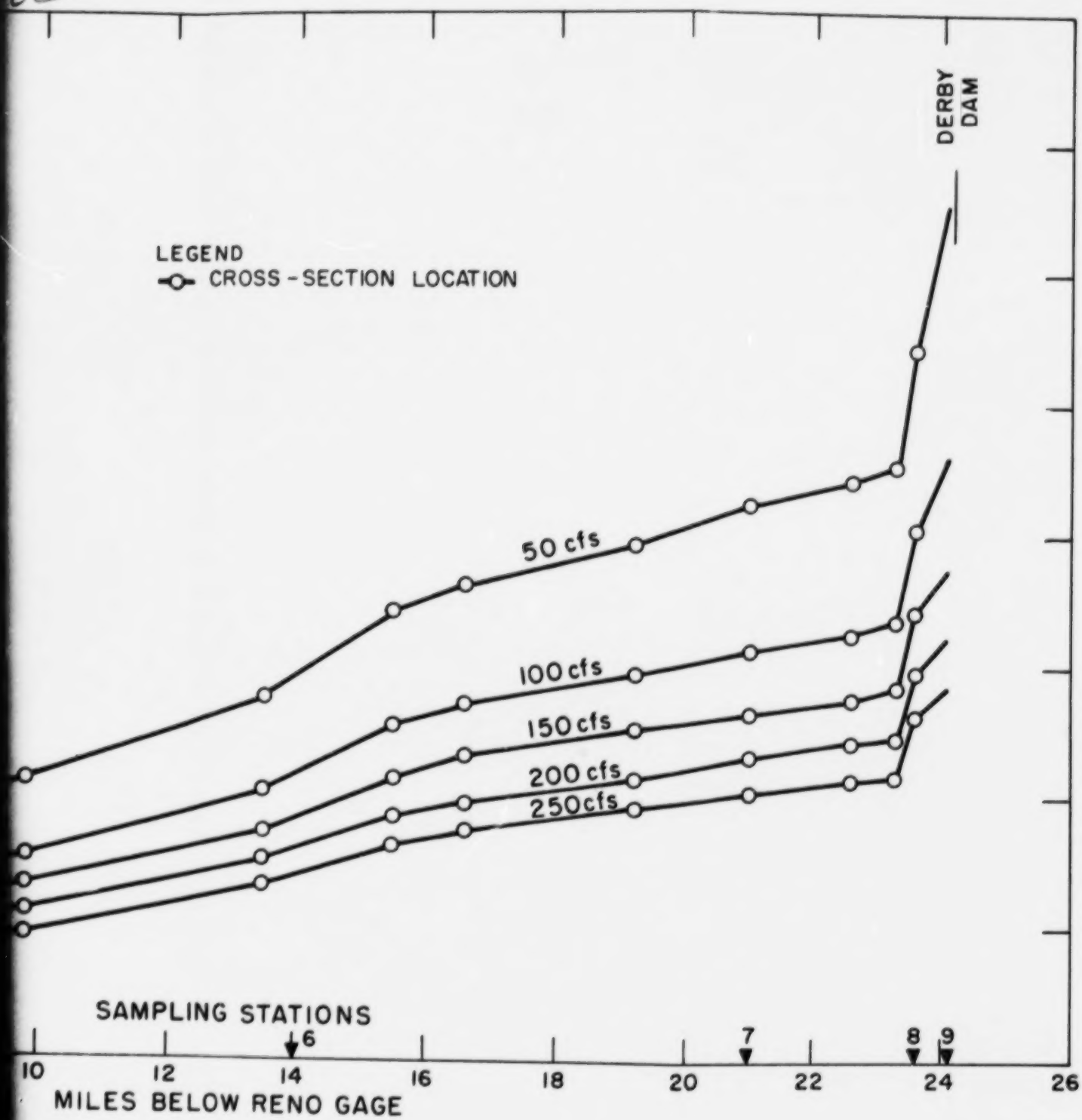
FIGURE 5



ACCUMULATED TIMES OF PASSAGE A

TRUCKEE RIVER

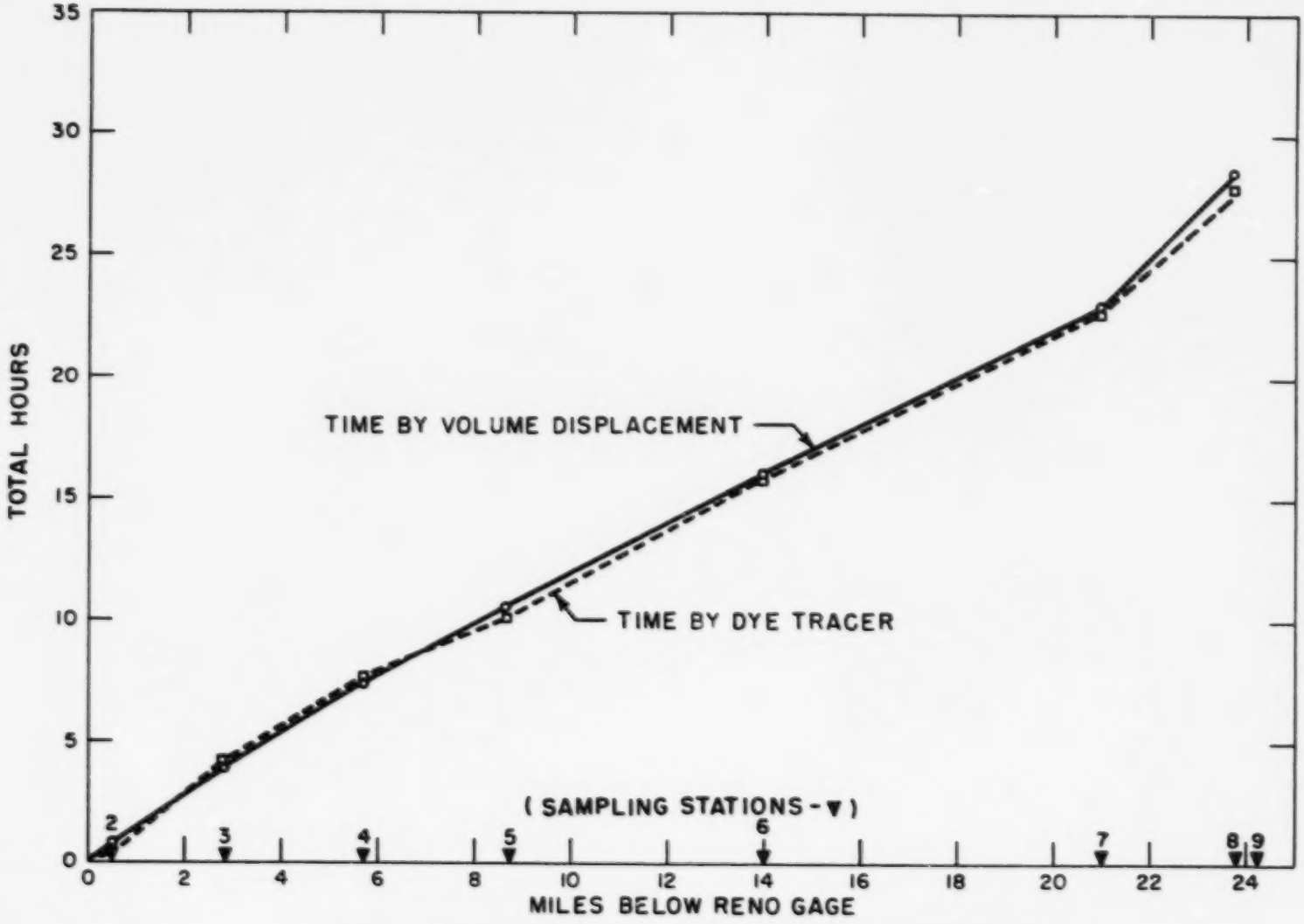
FIGURE 5



TIMES OF PASSAGE AT INDICATED FLOW

TRUCKEE RIVER

FIGURE 5



TIME OF PASSAGE - PREDICTED VS. OBSERVED
TRUCKEE RIVER
FIGURE 6

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Sparks Ditch a vertical rise of 0.2 hours occurs which is the time of passage in this short segment of the stream. If here an additional 25 cfs enter the river the total flow is then 225 cfs and a line midway between the 200 and 250 cfs lines must be used. Following this line from Sparks Ditch to Mile 8 a vertical rise of 2.2 hours is noted. The total time of passage from Mile 4 to 8, therefore, is the total vertical rise observed or 4.6 hours (2.2+0.2+2.2).

The data in Figure 5 were checked against results obtained from the dye tracer studies. The times of passage of the peak concentration of dye were plotted in Figure 6 as accumulated times in a downstream direction. From Figure 5 the predicted times at the particular flows encountered during the dye tests were obtained. These were plotted in a similar fashion and the agreement between the two sets of data is quite good. The flows occurring during the dye tests were from 170 to 345 cfs (Vista gage), which indicates the prediction method is quite accurate in this range.

STREAM BIOLOGY

A biological investigation measures the kind and quantity of life that inhabits a stream. Benthic organisms, which usually have life cycles of one year or longer, are especially suitable for evaluating streams, since they reflect bottom conditions over a period of several months. Many factors including (1) light, (2) temperature, (3) dissolved gases, (4) food supply, (5) type of bottom substrate, (6) water depth, and (7) current velocity effect the number as well as the kind of organisms that inhabit the aquatic environment. A change in any one of these factors will change the biota.

Rock and coarse gravel offer the most physically suitable bottom habitat; decreasing benthic productivity is correlated with decreasing particle size of substrate. Fine sand, because of its small surface area and shifting nature, offers little habitat to organisms.

Most forms of organisms are not equipped to move great distances; they are subjected to all adverse conditions entering the habitat. Some forms cannot adjust to changes within the habitat and are killed, whereas others can tolerate severe environmental changes. Organic pollution, for example, will cover the bottom substrate with sludge drastically increasing the food supply and decreasing the dissolved oxygen. Such environmental changes are sufficient to kill intolerant benthic forms (immature stoneflies, caddisflies, mayflies, etc.), but because of decreased predation and abundant food supply, offers ideal conditions for tolerant forms (sludgeworms and certain midge larvae). Thus, an unpolluted stream will support many different kinds of organisms while a stream carrying organic wastes will support a large benthic population, but only two or three tolerant species.

Inorganic silt also covers the bottom substrates and eliminates living spaces for benthic forms. It does not, however, offer a rich food supply; the silt suppresses benthic production of all forms.

Methodology

The influence of waste discharges on aquatic life in the Truckee River, Nevada, was evaluated by collections of organisms and stream observations during July 11-16, 1962. The river from the State Line to below Derby Dam is made up of many riffles and long shallow pools, with

the exception of the Derby Dam impoundment. The riffles were approximately 12 inches in depth and the pools 20 inches. The backwater area above Derby Dam ranged from a depth of one foot on the flats to 12 feet in the channel.

Most benthic collections were made at riffles because: (1) they were quite common, and (2) they were the most productive of bottom organisms. Bottom organisms were collected with the Surber stream bottom sampler. At all stations samples were taken at the mid-stream and the two-quarter points and the results averaged to obtain the number of organisms per square foot at each station. At Stations 8 and 9, in the Derby Dam impoundment, samples were collected with an Ekman dredge. The entire sample taken with the Surber sampler was preserved in the field; the Ekman dredge samples were washed in a U. S. Standard No. 30 sieve and then preserved. A dip net was used at all riffle stations to obtain additional qualitative information.

Algal samples were collected at all stations where attached algae were observed. Four water samples (Stations 1A, 3, 5, and 9) were collected and preserved for phytoplankton analysis.

Findings

Fourteen and sixteen kinds of organisms were found at Stations 1A and 1, respectively, including immature stoneflies, mayflies and caddisflies, which are associated with natural unpolluted streams (Table 4, Figure 7). The benthic population was three-fold greater at Station 1 compared to Station 1A. There was an organic sludge substrate (10 x 50 feet) near the Idlewild Park shore and organic enrichment may be responsible for the increase in midge larvae and sludgeworms at this station.

Table 4

Benthos Data - Truckee River - July 1962

Common Name	Genera[1] (or Higher Groups)	Stations 1A	1	2	3	5	6	7	8	9	10
Stonefly Nymphs	Isogenus	1	1	1	-	-	-	-	-	-	-
Caddisfly Larvae	Hydropsyche	2	14	3	-	7	225	150	-	-	191
	Cheumatopsyche	9	-	-	-	-	1	1	-	-	4
	Hydroptila	-	3	4	-	-	-	1	-	-	22
	Brachycentrus	-	-	-	-	-	-	-	-	-	1
Mayfly Naieds	Baetis	19	64	3	16	20	84	191	-	-	383
	Ephemerella	4	5	1	1	1	1	-	-	-	-
	Paraleptophlebia	-	1	1	-	-	-	-	-	-	-
	Tricorythodes	-	1	3	1	6	1	7	-	-	210
	Heptagenia	3	6	2	2	1	-	1	-	-	-
Beetle Larvae	Elmidae	-	1	-	-	-	-	-	-	-	-
	Dineutus	-	-	1	-	-	-	-	-	-	-
Moth Larvae	Parargyractis	1	-	-	-	-	-	-	-	-	1
True Fly Larvae	Hexatoma	1	1	-	-	-	-	-	-	-	-
	Tentipedidae	26	157	170	221	73	34	37	78	88	100
	Simuliidae	1	-	2	1	1	1	3	-	-	37
	Anthomyiidae	-	-	-	-	-	-	-	-	-	1
	Hemerodromia	1	1	-	-	-	-	-	-	-	11
	Palpomyia	-	-	-	-	-	-	-	-	-	1
Limpets	Ancylidae	-	-	1	-	1	5	-	-	-	-
Snails	Physa	-	-	-	-	-	-	-	-	-	31
	Lymnaeidae	-	-	-	-	1	-	-	-	-	-

Table 4 (Continued)

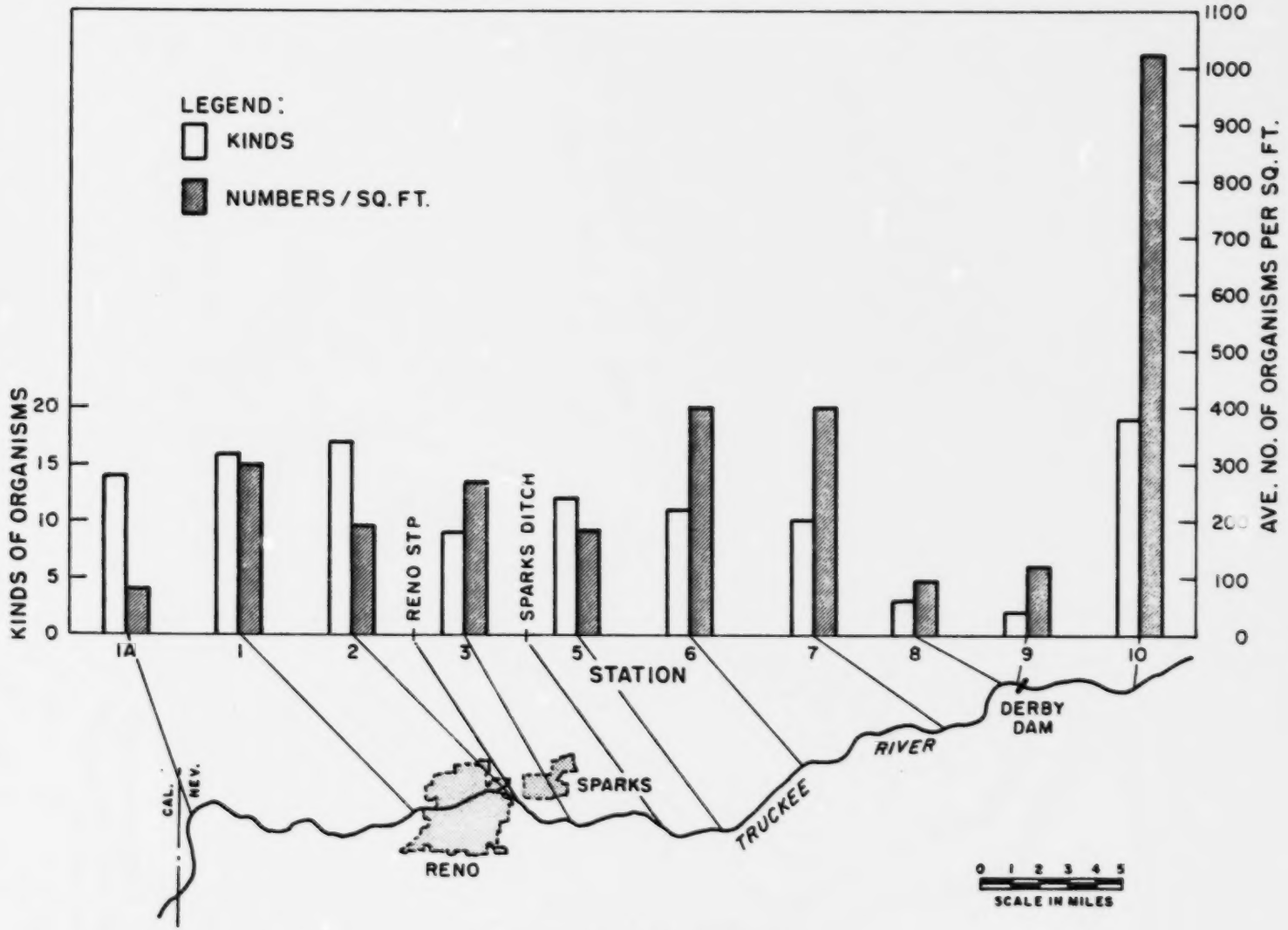
Benthos Data - Truckee River - July 1962

Common Name	Genera[1] (or Higher Groups)	Stations 1A	1	2	3	5	6	7	8	9	10
Crustacea	Decapoda	1	-	1	-	-	-	-	-	-	1
	Gammarus	-	1	4	-	20	1	2	-	-	9
	Hyalella	-	-	-	-	1	-	-	-	-	17
Roundworms	Nematoda	1	7	1	1	-	-	-	-	-	4
Segmented Worms	Oligochaeta	5	36	30	33	48	34	15	24	32	8
	Hirudinea	-	1	1	1	4	14	4	4	-	3
Average Number of Organisms per Sq. Ft.		75	300	229	277	184	401	477	106	120	1035
Kinds of Organisms		14	16	17	9	13	11	11	3	2	19

1 = Tentative Identification

Station 2 downstream from the city of Reno, but approximately 300 yards above the Reno Sewage Treatment Plant outfall, supported an abnormally profuse growth of a filamentous green alga (Cladophora) that was growing on all exposed surfaces in the stream except the finer gravel. The filaments of this alga were three to six feet in length and choked the stream bed for a distance of 900 feet. The number of benthic organisms at this station was slightly decreased, perhaps because of a reduction in favorable substrate surface which was occupied by the attached algae.

Station 3, below the Reno Sewage Treatment Plant outfall, was found to be somewhat biologically degraded. There was a reduction in numbers of sensitive benthic forms, and immature stoneflies and caddisflies were eliminated. Tolerant bloodworms and sludgeworms did not increase in numbers because there was no appreciable sedimentation of organic sludge, although there was a blanket of loose organic sludge one-quarter inch deep in the shallow low velocity areas at this station. The lack of Cladophora was quite evident compared to the profuse growth at Station 2. In its place the tolerant blue-green alga Oscillatoria and the green filamentous algae Stigeoclonium were quite evident. Sewage fly pupae (Psychoda) were collected at Stations 3 and 5, but were not considered in the benthic samples since they presumably originated in upstream sewage treatment plants.



BENTHIC ORGANISMS
TRUCKEE RIVER - JULY, 1962

FIGURE 7

16a

Biological conditions show definite signs of improvement at Stations 5, 6, and 7, when compared to Station 3, even though the Sparks treatment plant effluent is added to the river 2.7 miles above Station 5. Caddisfly larvae and mayfly naiads were present at Station 5 and have greatly increased in number at Stations 6 and 7; whereas, the more tolerant bloodworms decrease in abundance at these stations.

The tolerant algal forms found at Station 3 were not observed at Stations 5, 6, and 7; however, growths of Cladophora were present. Sparse growths of a rooted aquatic pondweed (Potamogeton) were present at Stations 5 and 6, but not at Station 7. A sewage odor was detectable at the riffles at Stations 5 and 6, but not at Station 7. Organic sludge was not observed at these stations, however, a fine silt was present in the shallow low velocity areas at all three stations. The effect of an environmental difference, on benthic production and diversification, between different habitats such as riffles and deep pools is quite evident at Stations 8 and 9, when comparisons are made with other stations sampled. An analysis of the benthos at Stations 8 and 9 in the Derby Dam impoundment did not indicate organic pollution. The kinds of benthic organisms were few and the low populations of these forms indicate limited organic deposition. The substrate was composed of fine clean sand and a sparse amount of terrestrial plant detritus. The one foot mud flat was composed of a fine silt which made up an appreciable part of the impoundment. A very thin layer of the alga Cladophora was observed on the silt substrate.

Station 10 (3.8 river miles downstream from Derby Dam) was considered in biological balance and in a state of high benthos productivity as compared to the upstream riffle stations. Over 70 per cent of the average number of benthic organisms were composed of clean water associated forms, such as caddisfly larvae and mayfly naiads. The algal and aquatic plant growth was abundant but not excessive.

Phytoplankton samples were collected from Stations 1A, 3, 5, and 9. Diatoms were the dominant forms; a progressive increase downstream in the total number of diatoms was indicative of organic enrichment. The number per ml. per station is as follows: 1A, 1310; 3, 7680; 5, 6380; and 9, 10,020.

During this survey natural reproduction of rainbow trout, Salmo gairdneri, was in evidence. Six eggs with developing embryos and five sac-fry were collected at Station 1, two sac-fry were collected at Station 2, and two advanced fry were taken at Station 3. The latter station was downstream from the Reno sewage treatment plant effluent. The specimens taken at Stations 1 and 2 were, no doubt, deposited, incubated and/or hatched at these locations since rainbow trout fry do not emerge from the gravel of the spawning bed (redd) until the yolk sac has been absorbed. At Station 3, however, the possibility of residence or migration of the two actively feeding fry did exist. No further evidence of trout reproduction was found below Station 3.

The interrelationship of nutrients, temperature and turbidity greatly affect aquatic life in the stretch of stream from Station 2 to

Station 10. Increases in these characteristics would be expected as a result of (1) natural land drainage, (2) sewage treatment plant effluents, (3) irrigation return waters, and possibly (4) minor outfalls in the cities of Reno and Sparks.

Below the entrance of the Reno plant effluent algal growths were in evidence only at riffles and other shallow areas where the bottom was within the euphotic zone and where little deposition occurred. Therefore, the benthos on most riffles maintained population levels comparable to the control Stations 1A and 1. The exception was Station 10 which showed an increase in biological production. This may have been brought about by the combined effects of reduced turbidity through settling in the Derby Dam impoundment, increased temperatures, and shallower depths. These factors permit an increased depth of light penetration, resulting in greater algal and aquatic plant growth.

ANALYTICAL RESULTS

As a result of the stream sampling procedures discussed previously at least 24 samples were obtained at each station during the first seven-day study period. In addition, special sample runs during the second week provided additional data. All of the analytical data obtained during the entire survey period are summarized in Tables 5 and 6.

Stream Data

The dissolved oxygen stream data in Table 5 exhibit an extremely wide range at certain stations, suggesting daytime photosynthetic oxygen production and oxygen consumption through respiration during nighttime

Table 5

Summary of Dissolved Oxygen Results

Station*	No. of Samples	D. O. (ppm) Min.	Tenth Percentile	Median	Ninetieth Percentile	Max.
1	40	6.5	7.2	7.9	9.0	9.9
2	44	6.7	6.9	7.7	9.4	11.2
3	49	3.9	4.4	7.6	10.2	13.5
4	48	3.7	3.9	7.3	9.9	12.4
5	48	3.5	4.9	5.9	7.2	7.5
6	48	4.9	5.2	6.1	7.3	7.4
7	46	5.5	5.9	6.7	8.0	8.5
8	44	5.2	5.6	6.6	8.0	8.9
9^S	46	4.7	5.4	6.8	11.5	15.6
9^B	31	5.2	5.4	6.6	9.4	12.8
10	28	4.8	5.0	7.1	12.3	12.8
RSTP	32	1.2	1.7	2.2	3.3	3.6
SSTP	28	2.2	2.2	2.5	4.7	5.1
SD	50	1.4	1.6	3.4	5.4	6.1

* Descriptions given in Table 3

Table 6

Summary of BOD and Temperature Results

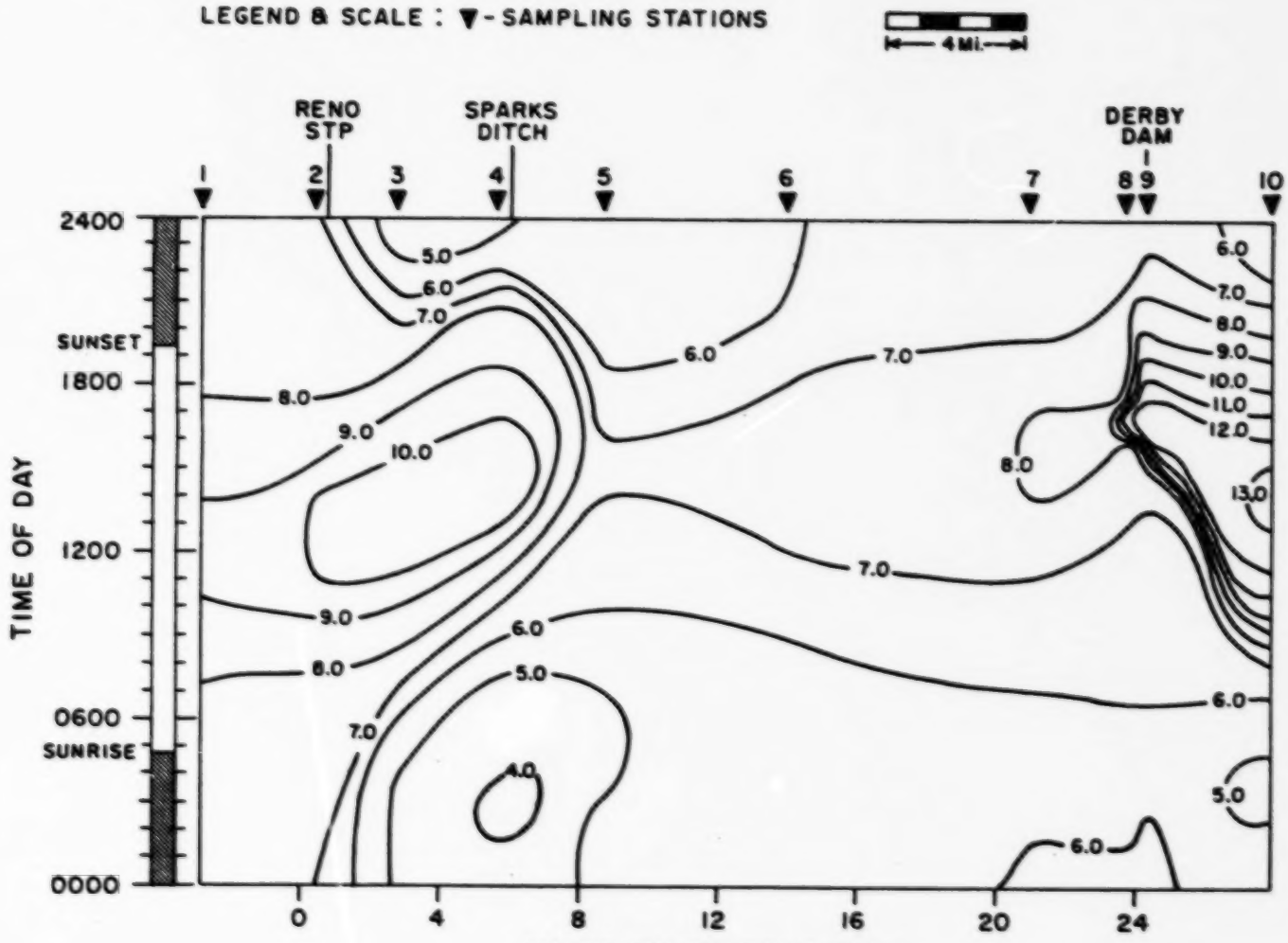
Station*	Biochemical oxygen demand (BOD) 2-day-20°C (ppm) Min.	Median	Max.	Temperature °C Min.	Mean	Max.
1	1.0	1.4	[illegible]	14.0	18.5	25.0
2	1.0	1.6	> 7.6	14.5	18.9	23.5
3	3.2	5.3	> 7.5	15.5	20.1	27.0
4	2.5	5.1	> 7.3	15.0	20.4	27.0
5	3.2	5.7	> 6.9	16.0	20.3	26.0
6	2.9	4.7	6.1	16.5	20.8	24.0
7	2.9	3.9	6.2	16.5	21.0	25.0
8	2.4	3.4	5.3	16.0	21.2	26.0
9S	2.8	3.4	> 6.6	16.5	21.4	27.0
9B		-		17.0	20.1	25.5
10	2.3	2.9	5.1	14.5	19.9	28.5
RSTP	7.6	23.	39.	20.0	22.4	25.5
SSTP	24.	68.	102.	16.5	18.5	21.0
SD	3.0	9.2	18.	15.0	21.3	30.0

* Description given in Table 3

hours. Considering the tenth and ninetieth percentiles (which contain the "middle" 80 per cent of the data) this range was greatest at Station 10 where it was 7.3 ppm. Station 9 at Derby Dam had a range of 6.1 ppm at the surface and 4.0 at the bottom. Of the upstream stations, Stations 3 and 4 had high ranges of 5.8 and 6.0 ppm, respectively. All of the other stream stations had a range near 2 ppm. The lowest stream DO values found were at Station 4 where five observations were between 3.7 and 3.9 ppm. The lowest single value observed was at Station 5 and was 3.5 ppm. All of these low values were found just before sunrise.

Because of the great diurnal effects noted in the stream DO it is not reasonable to attempt to use average values to portray conditions at each station. To present a complete picture of stream quality, time of day as well as location must be considered. The isopleths shown in Figures 8, 9, and 10 are useful for depicting these variations. From Figures 8 and 9, for example, one can note that the DO concentration usually found at Station 4 at 4:00 AM was less than 4 ppm or 50 per cent saturation, while at 3:00 PM it was greater than 10 ppm, or 130 per cent saturation. These isopleths were constructed by plotting all of the data for a given station versus time of day. A smooth curve was fitted to these data as representative of "average" conditions during the entire survey period. Hourly values from this curve were then used to plot the isopleth.

The DO isopleths show that in the upper stretch the maximum values will be found at Station 3 during midafternoon, while the lowest will be found at Station 4 at sunrise. This latter observation could be useful

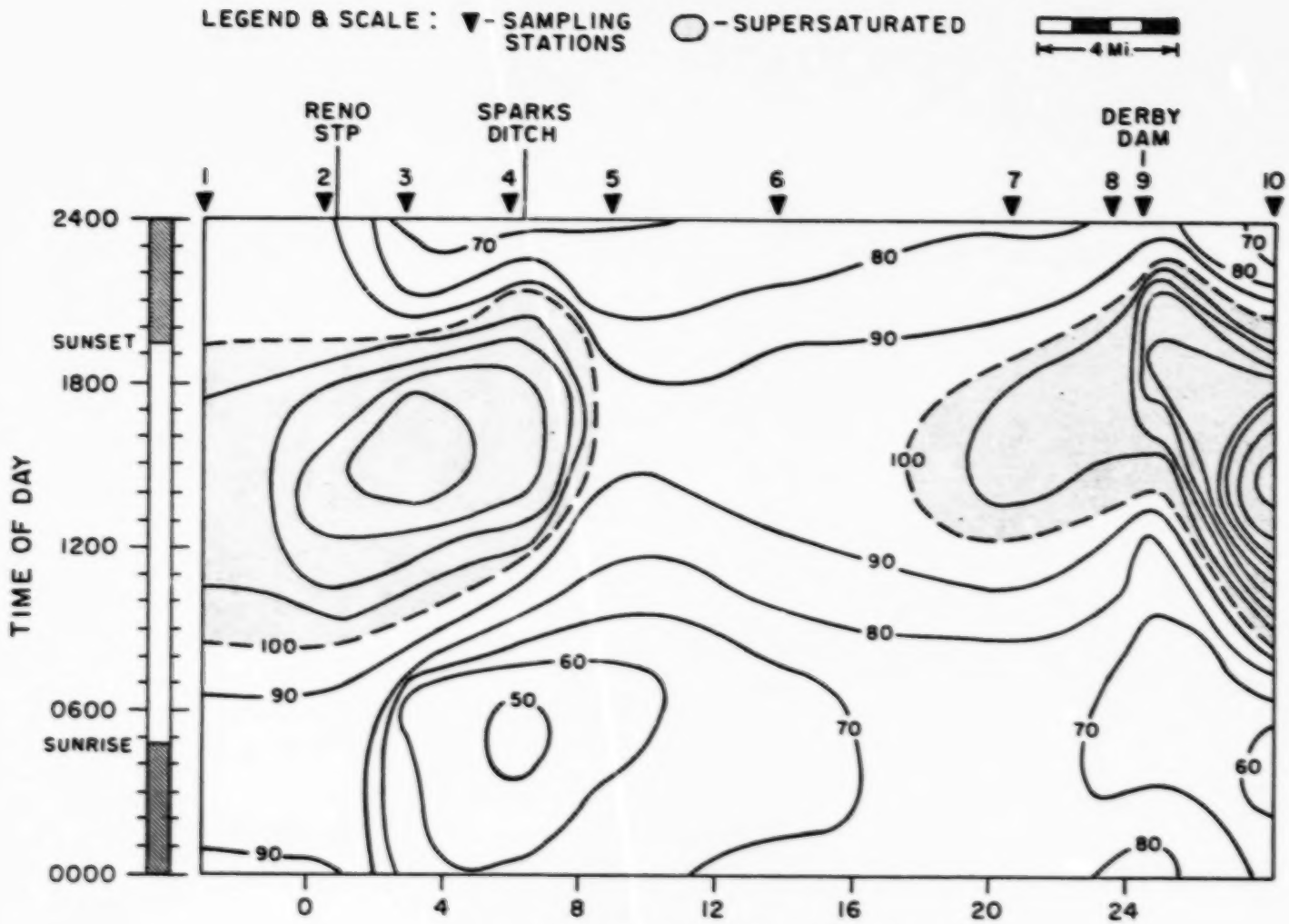


DISSOLVED OXYGEN-(ppm)

TRUCKEE RIVER-JULY, 1962

FIGURE 8

22a

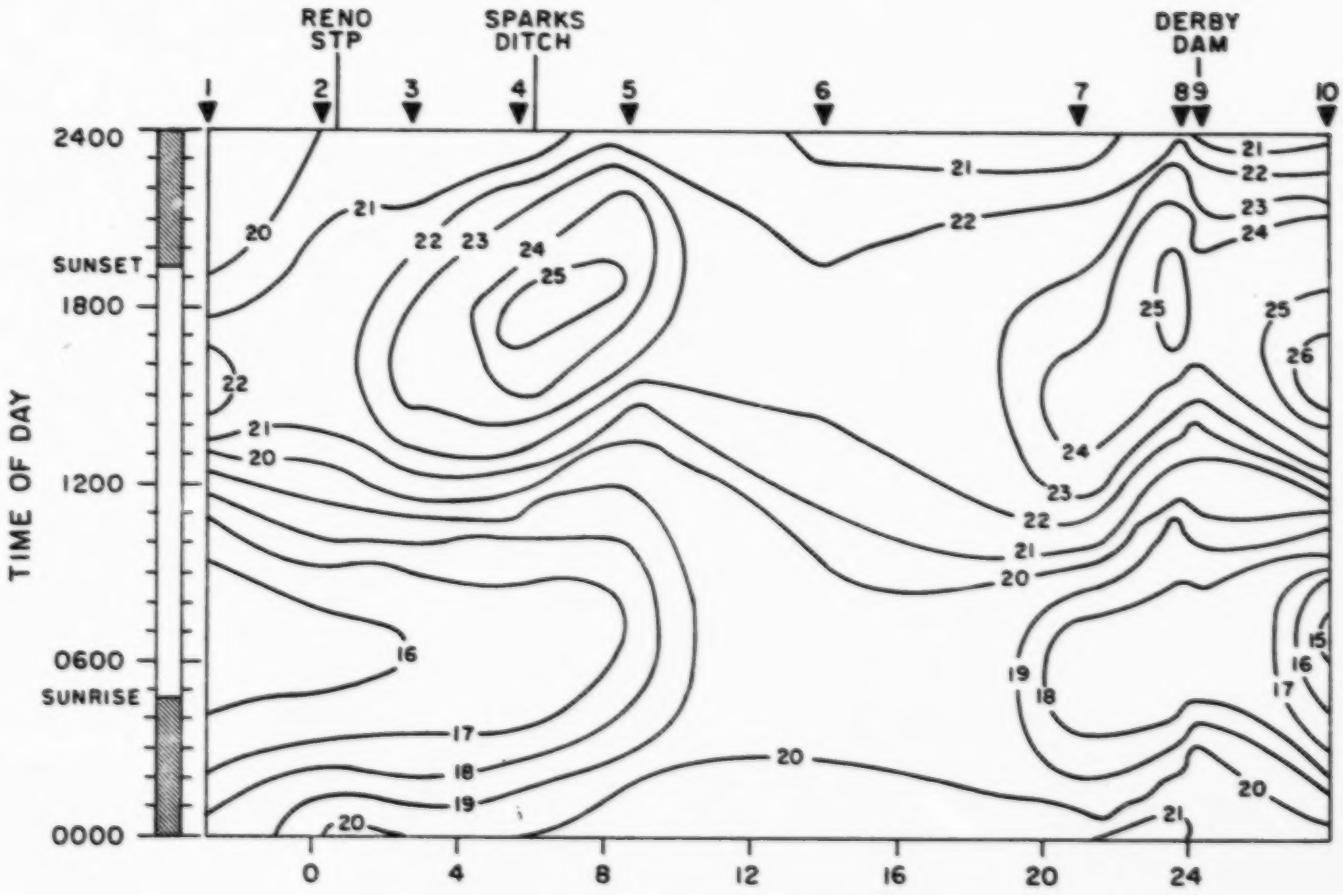


DISSOLVED OXYGEN (% SATURATION)

TRUCKEE RIVER - JULY, 1962

FIGURE 9

226



TEMPERATURE - (°C)

TRUCKEE RIVER - JULY, 1962

FIGURE 10

for stream monitoring purposes. Samples taken routinely at Stations 3, 4, and 5 at sunrise should reveal the extent of the most critical DO depletion in the river.

It may be noted from Station 5 to beyond Station 6, a distance of about ten miles, there is very little downstream change in DO at any given time of day. Horizontal cross-sections of the isopleth (Figure 9) taken at 5:00 AM and at 3:00 PM as plotted in Figure 11 reveal this clearly. Vertical cross-sections of Figure 9 were taken at Stations 4 and 6 and are plotted on Figure 12. Both of these plots show the typical diurnal variations produced by photosynthetic organisms, though their amplitudes differ.

The stream water temperature data in Table 6 and Figure 10 also exhibit wide variations. There is a steady downstream increase in mean temperature from 18.5°C. at Station 1 to 21.4°C. at Station 9. More noteworthy, however, is the range of temperature encountered at each station which was as high as 14.0°C. (25°F.) at Station 10. The diurnal variations shown in Figure 10 reflect the wide daily range of ambient temperatures (45.5°F. in July) as well as the shallow depths and high turbulence of the river at these flows. The mean river depth and velocity, excluding the Derby Dam impoundment, was about 20 inches and 1.2 fps, respectively.

The effect of the Reno effluent discharge is apparent at Stations 3 and 4 where somewhat higher temperatures (over 25°C.) are found. These higher levels continue beyond the entrance of Steamboat Creek and Sparks

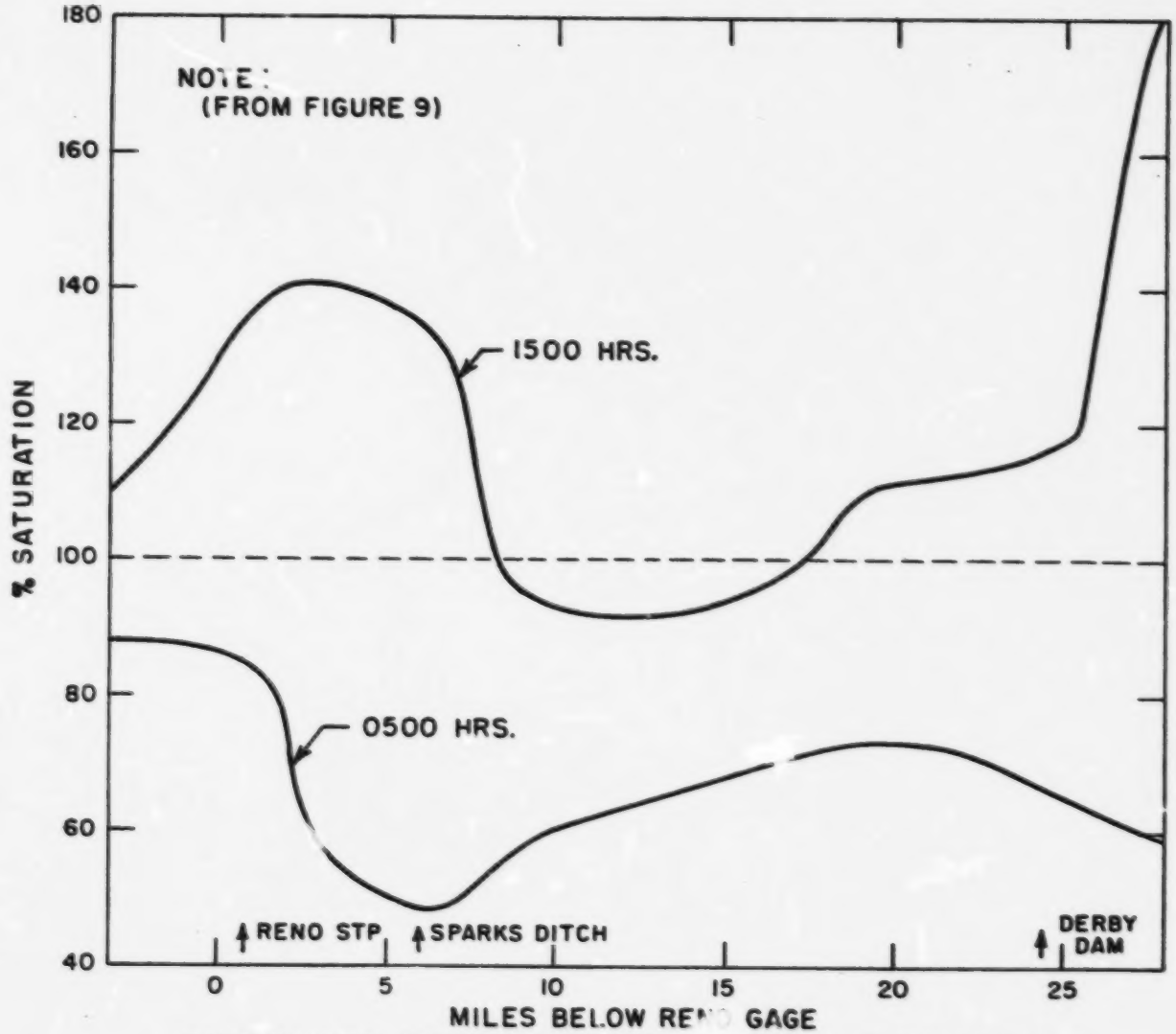
Ditch to Station 5. Between this location and the impoundment diurnal variations are less.

The results of the limited chemical analyses performed on stream samples are shown in Figure 13. These show that significant increases in phosphorus and the ammonia and organic forms of nitrogen occur immediately below the waste discharge points. A steady decrease in ammonia, accompanied by an increase in nitrates, indicates that nitrification is taking place in this stretch of the river. The nitrate and phosphate levels throughout the stream length under study are more than adequate to support a high level of algal activity.

Figure 14 gives coliform bacteria results for two sets of samples collected at all river stations and at each effluent discharge. The set of samples collected on the 12th reflects the effects of the rainfall which occurred that morning. On this day the Reno chlorinator was ineffective as compared to the sample collected on the 24th. Storm overflows also added to the bacterial numbers in the stream. More effective chlorination at the Reno plant and the absence of surface runoff and storm overflows resulted in much lower values at Stations 3 and 4 on the 24th. The high bacterial level in the Sparks effluent on that day, however, caused downstream concentrations to be as high as on the 12th. Because of the lack of sufficient samples at each stations, reliable estimates of bacterial dieoff rates in the river are not possible.

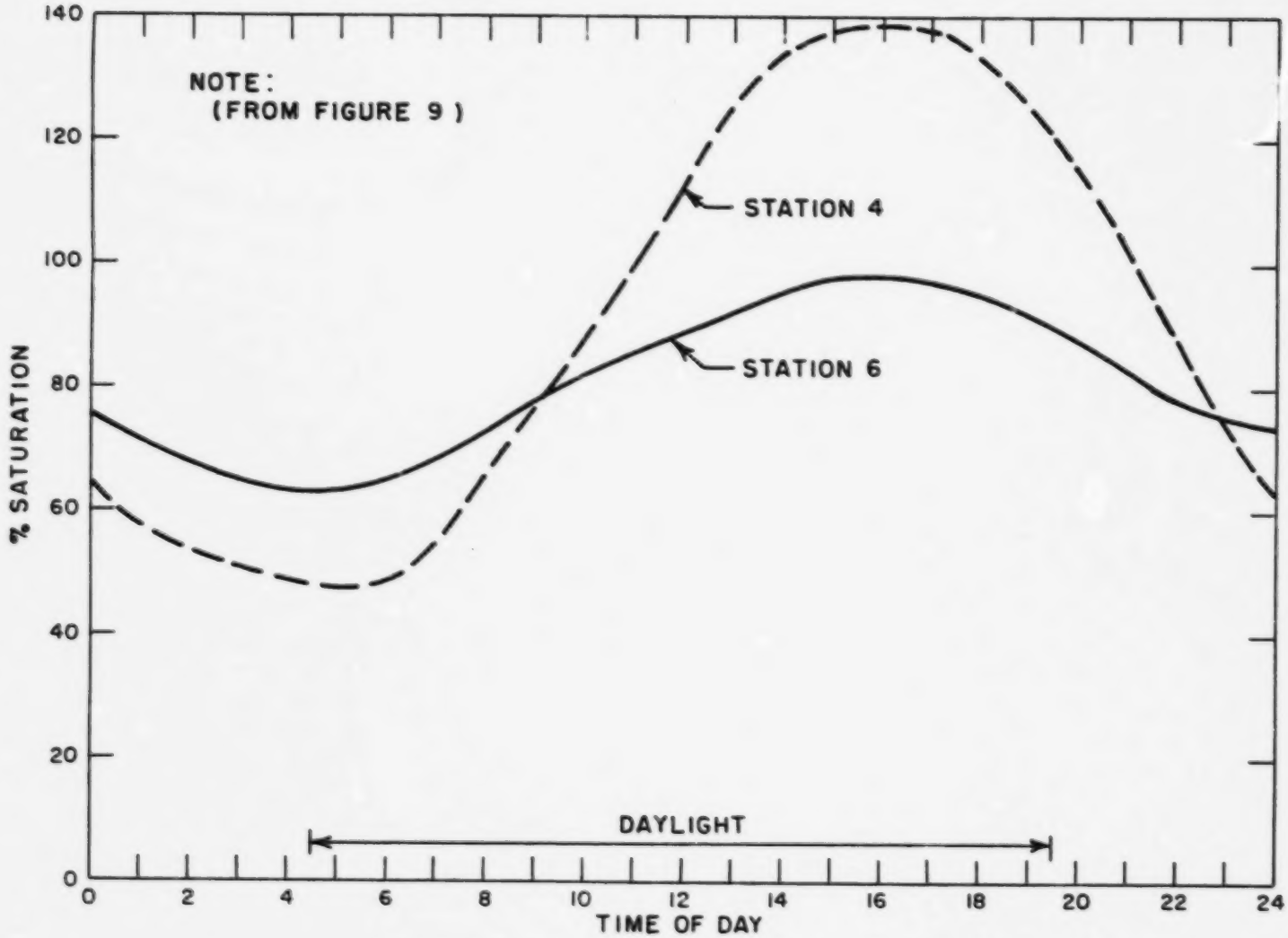
Treatment Plant Data

Tables 5 and 6 also contain information on treatment plant effluent samples. These data show the DO content of both plant effluents to be



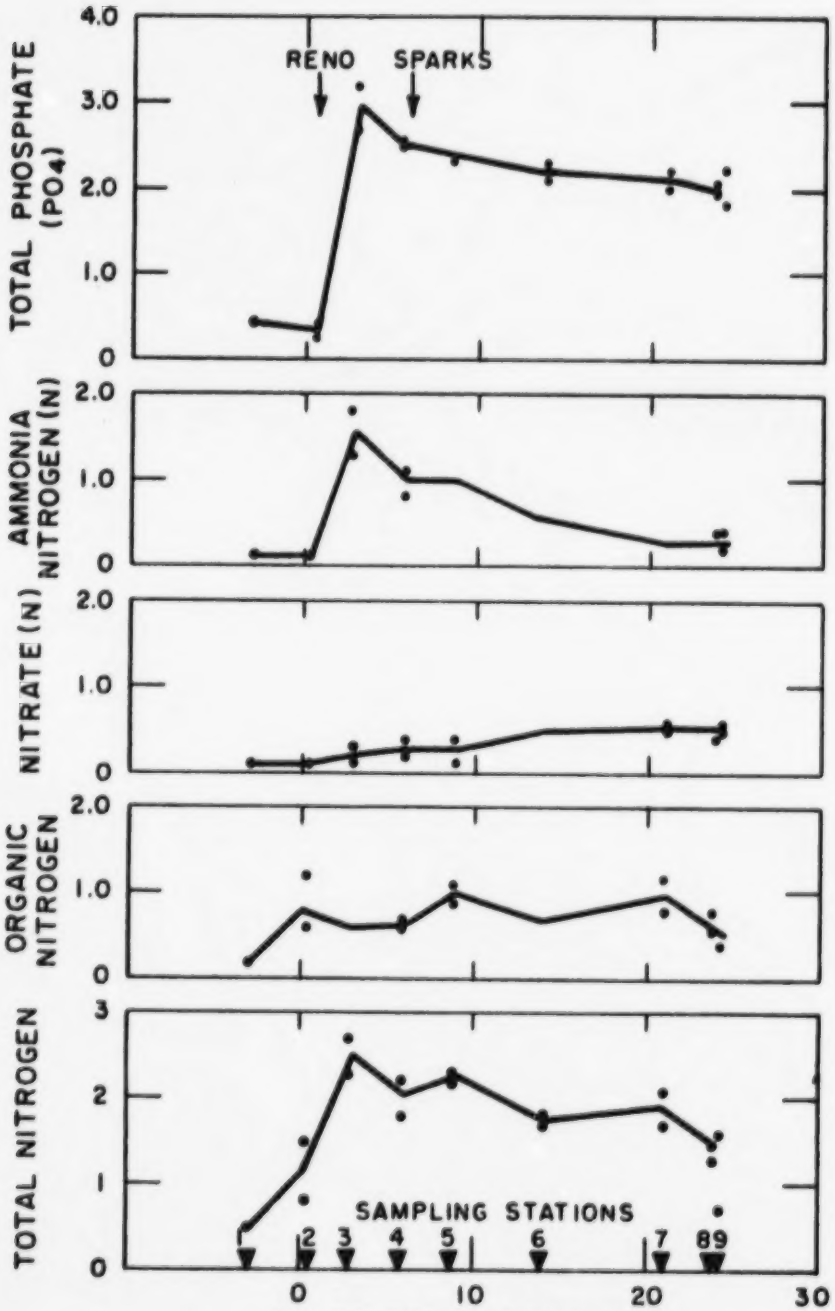
DISSOLVED OXYGEN - % SATURATION VS. RIVER MILE
TRUCKEE RIVER

FIGURE 11



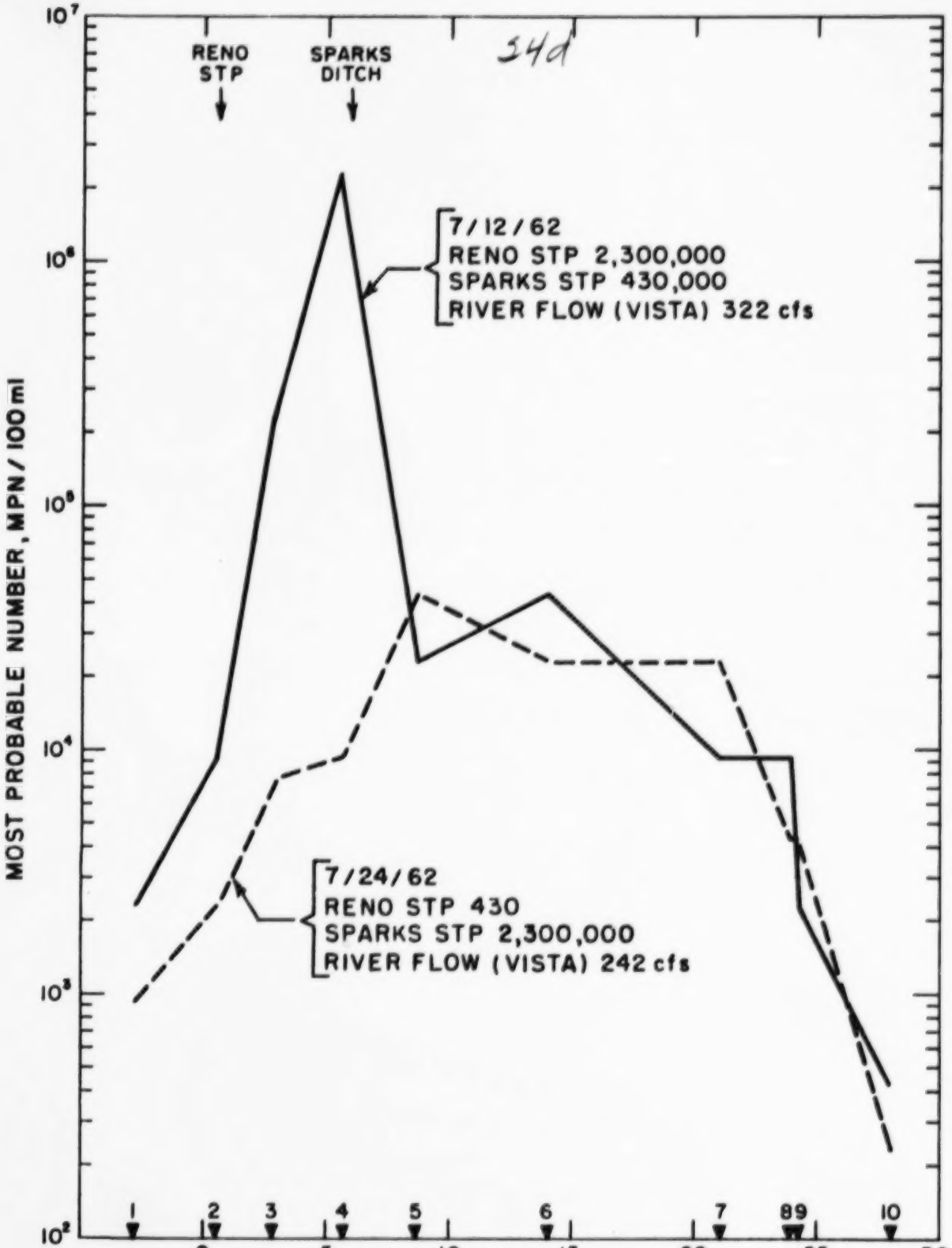
DISSOLVED OXYGEN - % SATURATION VS. TIME OF DAY
TRUCKEE RIVER

FIGURE 12



NUTRIENT LEVELS (PPM)
TRUCKEE RIVER

FIGURE 13



COLIFORM BACTERIA
TRUCKEE RIVER

FIGURE 14

quite comparable, each having a median concentration slightly above 2 ppm. The Reno effluent was, on the average, 4°C. warmer. The BOD of the six-hour composite samples varied at Sparks, from 24 to 102 ppm and a median value of 68. ppm. The effluent BOD also varied at Reno by a factor of five, from 7.6 to 39.ppm, with a median value of 23. Samples of these effluents were collected at a point following chlorination and as a result, it could be expected that the BOD reaction would be depressed somewhat due to the depletion in bacterial numbers. This depression will vary with chlorine dosage which did not appear to be consistent. The effect of this on the BOD results obtained is discussed in a later section dealing with deoxygenation rate curves.

On two different days four sets of six-hour composite samples of bot influent and effluent were collected at each plant. Treatment efficiencies on these days were calculated to be 85 and 89 per cent at Reno and 29 and 31 per cent at Sparks. The Reno efficiencies were based on unchlorinated effluent while the Sparks samples were collected after chlorination. The extremely low efficiency for a trickling filter plant as at Sparks is probably attributable to hydraulic overloading and/or short circuiting within the treatment units. This was evidenced by the results of a dye test of time of flow through the entire plant that were conducted at Sparks. Also a single composite sample of Sparks effluent was analyzed for settleable and non-settleable BOD. This showed that 35 per cent of the effluent BOD was settleable and indicates very inadequate secondary clarification. It was noted earlier that the Sparks effluent temperature was 4°C. cooler than at Reno and this too could indicate a shorter plant detention period although the residence

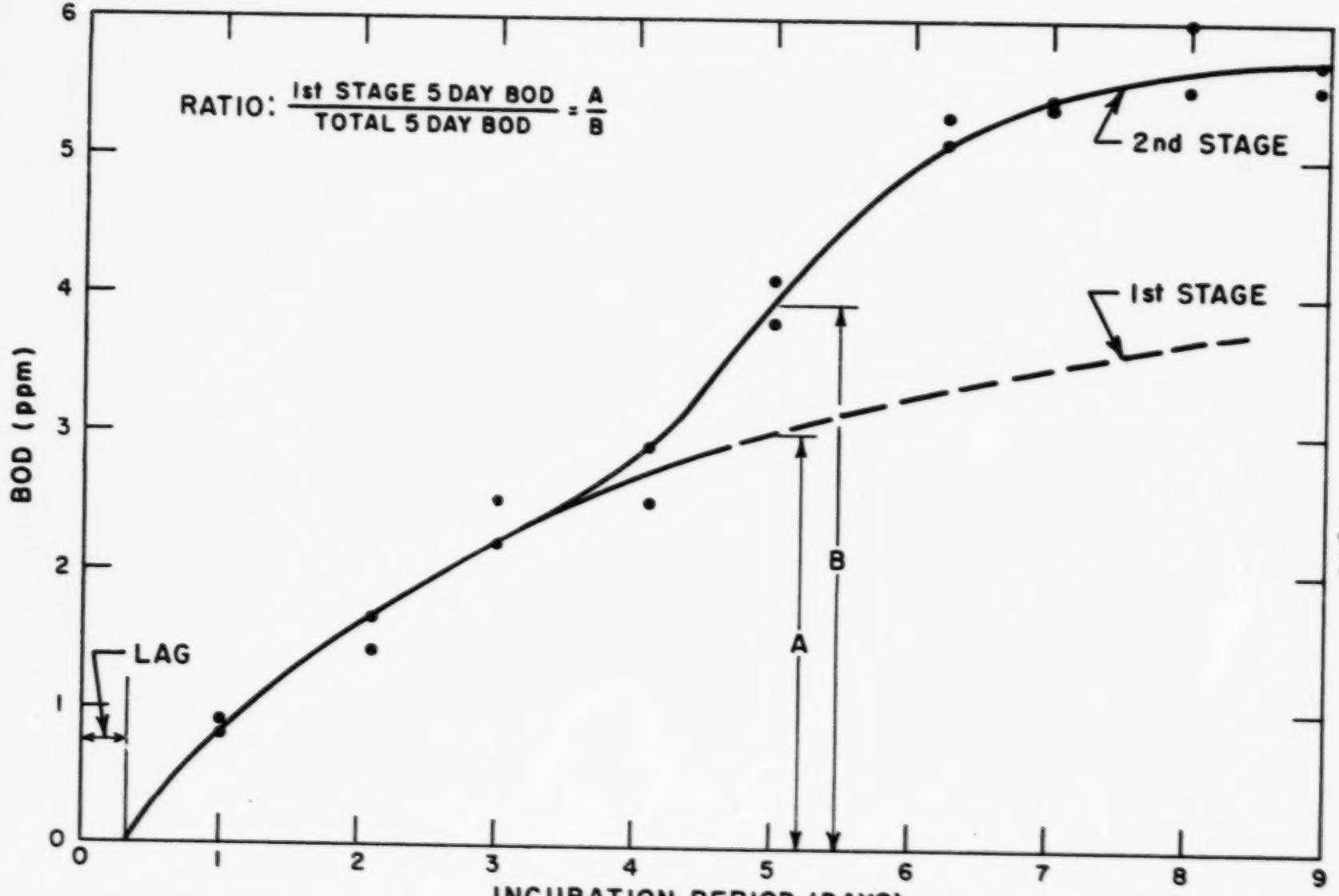
time in the larger Reno sewerage system is probably the primary cause of this difference.

In a later section dealing with BOD load integration, the above comments have been taken into consideration in estimating the actual load reaching the river from each of these plants.

Deoxygenation Rate Curves

A total of about 30 BOD time series were carried out on stream and treatment plant samples. Monomolecular curves of the type $y=L(1-10^{-k_1 t})$ were fitted to these time series data. These curves provide valuable information on the rate of the deoxygenation reaction at the point being sampled. Figure 15 is a representative curve which was obtained from a sample from Station 4 in the river. A summary of all of the rate curve data is contained in Table 7.

The deoxygenation rate constant, k_1, from the stream samples had an average value of 0.21 which is slightly higher than is usually encountered. Probably due to the fact that the Reno effluent is undergoing nitrification prior to discharge, all of the stream samples below the Reno discharge exhibit a very definite second stage as in Figure 15. The time onset of this second stage varied from about 3.5 days in the upper stretches to one day in the lower stretches. As a result, the five-day BOD depletions obtained on these stream samples were actually due to both carbonaceous and nitrogenous demand. The fraction of the five-day BOD which was due to the carbonaceous or first stage only was calculated as shown in Figure 15. This ratio which was unity above the Reno discharge point varied from about 0.65 immediately below the discharge down to



DEOXYGENATION RATE CURVE - STATION 4
TRUCKEE RIVER

FIGURE 15

Table 7

Deoxygenation Rate Curve Data

Station	k_1 1st stage	lag (days)	Start of 2nd stage (days)	1st stage BOD_5 total BOD_5 (A/B in Fig.15)
1	0.18	0	8	1
2	0.26	0.5	8	1.0
	0.20	0	4	0.86
3	0.24	0	2.5	0.54
	0.25	0	3.5	0.69
4	0.19	0.3	3	0.61
	0.25	0	2	0.60
	0.13	0.3	3.5	0.76
5	0.20	0.0	2.5	0.60
	0.16	0.3	3.5	0.60
6	0.12	0	3.5	0.66
	0.16	0	2.5	0.50
7	0.182	0	1.5	0.43
	0.20	0	2.5	0.42
8	0.21	0	2.0	0.47
	0.13	0	2.5	0.56
9	0.25	0	2.0	0.51
	0.28	0	1.0	0.47
	0.25	0	1.0	0.38
10	0.24	0	3.	0.72
	0.06	0	0.	0.0
Reno STP	0.21*	0.3	4.5	0.9
	0.46	0.7	3.5	0.68
	0.18	1.5	9.	1
Sparks STP	0.21	0	7.	1
	0.31	0.5	7.	1

* Unchlorinated; all other STP samples followed chlorination.

about 0.45 at Derby Dam. One sample at Station 10 below the dam appeared to be made up entirely of nitrogenous demand.

Since the time of flow from the upper to the lower end of the stream under study is about one day at these flows, it is the first stage demand that is of most value to the interpretation of this stream data. Therefore, in the integration of flowing BOD loads in the stream ratios similar to those in Table 6 may be used to convert the five-day BOD values reported to first stage BOD values.

The Reno STP effluent curves all exhibited lag periods, one being as long as 1.5 days. This undoubtedly is an effect of chlorination which reduces bacterial populations and retards the onset of the BOD reaction. In this case the BOD measured at five days is actually a 3.5 day demand and at this rate of reaction is only 88 per cent of the total demand exerted in the five days following the onset of the reaction. The Sparks STP effluent did not exhibit such lags nor did they enter the second stage as soon as the Reno samples indicating less nitrification taking place within the treatment process than at Reno.

ANALYSIS OF FINDINGS

BOD Load Balance

The information already presented has been used to achieve a balance in BOD loads entering and those observed at each river station. As a first step, each five-day BOD concentration was multiplied by the flow occurring at the time of sampling, yielding a five-day BOD flow rate in pounds per day. The five-day values were then converted to ultimate

first stage BOD using an appropriate k_1 rate as determined by deoxygenation rate curves. A representative value for the stream stations of 0.21 was used. This value was also applied to the Sparks effluent. For the Reno effluent a lag of 1.5 days and a k_1 of 0.18 was used.

The four-day period from July 13 to July 17 was chosen for this balance minimizing the effects of the rainfall and associated storm overflows of the previous day. The ultimate BOD flow rates were plotted in a manner similar to that shown in Figure 16. It was readily apparent that incoming loads and stream loads did not balance. This was particularly true above and below the Reno outfall where the increase in stream load was about twice that discharged by the plant. However, a reasonably good balance was achieved by correcting the BOD at those stream stations where the onset of the second stage demand was observed to occur before five days. This involved calculation of the ratio $\frac{A}{B}$, as shown in Figure 15 and listed in Table 7. These ratios were generally near 0.60 for stations below the Reno outfall. Although the ratios appeared to drop slightly with distance downstream, the curves of these lower stations were actually not as well defined and the value of 0.60, therefore, was applied generally to all river samples below Reno. The data resulting after applying this correction are plotted in Figure 16 and show a reasonably good balance of loadings. The loads resulting from this balance are listed in Table 8.

It would be well to note at this point the potential error involved in BOD flow estimates such as those shown in Table 8. For example, the ultimate BOD concentrations at Stations 1 and 2 had

Table 8

Truckee River Organic Loadings

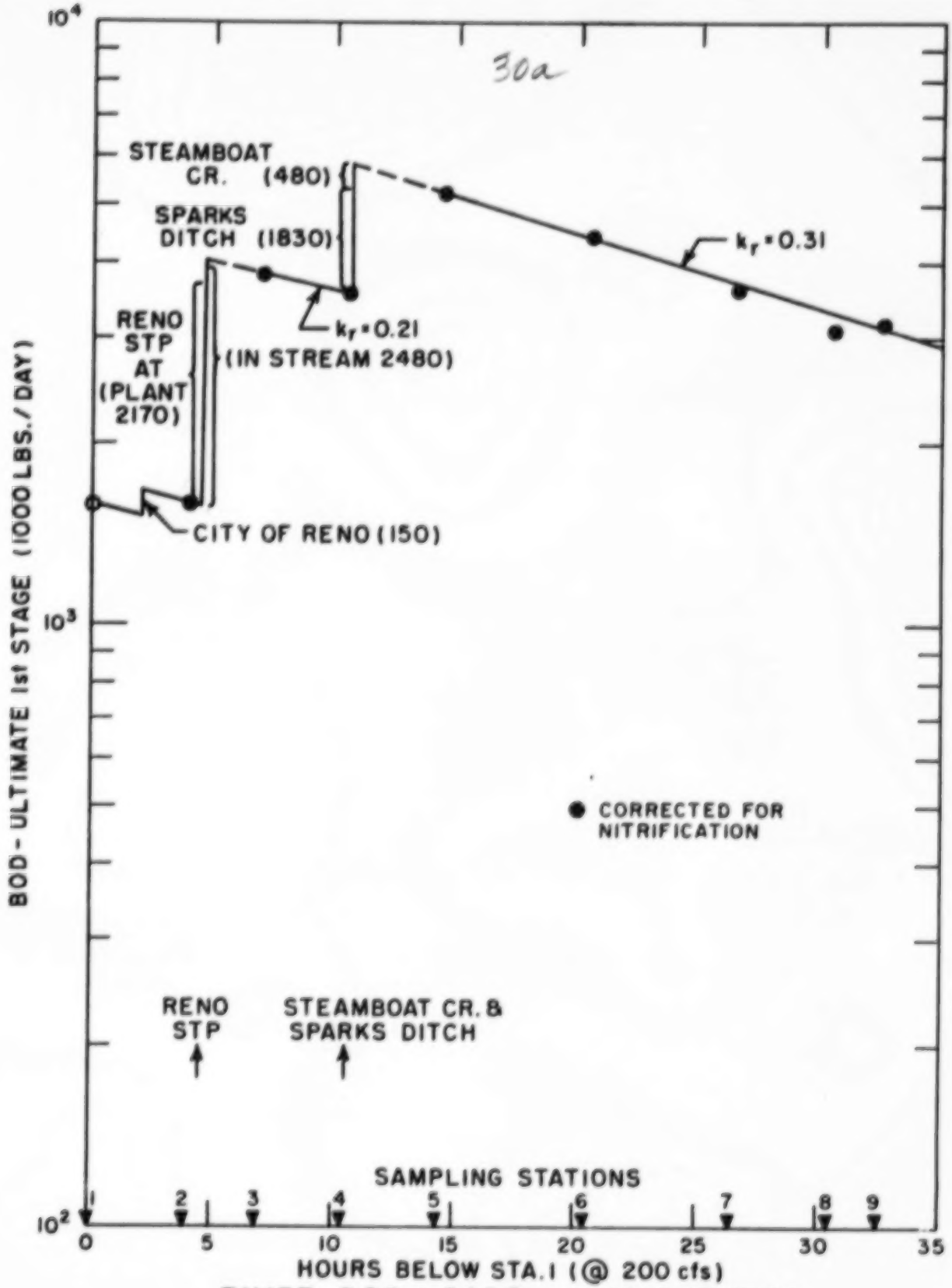
Estimates based on Figure 16

July 14-17, 1962

Source	River Mi.*	Flow (cfs)	Ultimate BOD (1st stage) (ppm)	(lbs/day)		% of Total
Upstream	above -2.8	180	1.6	1600		24.5
Unknown (City of Reno)	-2.8 to 0.0	-	-	150		2.3
Reno STP	0.7	15	31.	2480		37.9
Steamboat Creek	5.7	45	2.0	480		7.3
North Truckee Drain		25	2.0	270	4.1	
Sparks STP		6	48.	1560	23.9	
Sparks Ditch	6.0	31	11.	1830		28.0
				6540		100.0

* Below Reno gage

median values of 1.6 and 1.8 ppm, respectively. This slight difference resulted in the estimate that 150 pounds of BOD entered the river between Stations 1 and 2. Actually the slight difference in BOD at these two stations is probably not within the accuracy of the analytical method at these low levels and the change between stations may be only apparent. The data of Figure 13 support this likelihood, in that they do not indicate significant nutrient additions of sewage origin above Station 2. Another complicating factor is the possible presence of algae in the BOD samples which can lead to erroneous results. Finally the onset



RIVER BOD LOADS - JULY 14-17, 1962

TRUCKEE RIVER

FIGURE 16

of nitrification before the fifth day of incubation greatly affects 5-day BOD tests results. While an attempt was made to correct for this latter factor such a correction can only be an approximation.

The corrected increase in stream BOD (ultimate) due to the Reno discharge agrees reasonably well with the BOD actually measured in the effluent (2480 versus 2170 lbs/day).

However, the loading shown in Table 8 for the Sparks STP effluent, 1560 lbs/day, is considerably less than the load measured leaving that plant. The measured plant effluent load of 3060 lbs/day could not be accounted for in the Sparks Ditch or in the river. Considering this and the findings regarding settleable BOD in the effluent mentioned previously, it is possible that as much as 50% of the BOD load discharged by the Sparks plant may have settled out in the drainage ditch prior to entering the river. The upper end of the ditch was not actually examined to verify this. The total load in Sparks Ditch was allocated as shown in Table 8: 270 lbs/day to the North Truckee Drain and 1560 lbs/day to the Sparks effluent after sedimentation in the upper end of the ditch. A load of 480 lbs/day was allocated to Steamboat Creek so that a combined load of 750 lbs/day or 11. per cent of the total load entering the system was attributed to these irrigation return flows.

The apparent rate of BOD removal in the stream, k_r, was found to be 0.21 between Stations 2 and 3. This equals the deoxygenation rate, k_1, chosen for the entire stream. Below Station 4, however, a k_r value of 0.31 fits the data quite well. This is rather high although similarly high values have been found by others in shallow, turbulent streams such as the Truckee.

In the Truckee River, however, the erratic nature of the onset of the second stage reaction tends to obscure the actual rate of removal in the river. Others have indicated that relatively high rates of BOD removal may be due to such factors as sedimentation, turbulence, and attached oxidizing growths. Sedimentation is not believed to be an effective factor here.

Photosynthesis and Respiration

From the data presented previously it could be expected that the primary cause of the large diurnal DO variation in the Truckee River is the daytime photosynthetic oxygen production and nighttime oxygen-consuming respiration of the stream's algal growths. The location of both the maximum and minimum DO levels in the upper stretch, at Stations 3 and 4, respectively, correlate well with the location of maximum algal activity. The extensive nighttime oxygen consumption due to algal respiration which takes place above the Reno outfall is accompanied by oxidation of the Reno BOD load below the outfall to cause minimum DO conditions in the vicinity of Station 4 at sunrise. The addition of the oxygen-poor Reno effluent further compounds the deficit below the outfall.

In an effort to determine the extent to which each of the above effects contribute to the critical conditions observed at Station 4, the river was sampled for dissolved oxygen on two special "dye" runs. In each of these instances a quantity of dye (Rhodamine B) was added to the Reno STP effluent. The stream below the entrance of the effluent was monitored for the appearance of dye at each sampling station. Samples for DO analysis were taken at the first appearance of the dye, at the time the peak dye concentration was observed and at one hour subsequent

to passage of the dye peak. As the dye mass moved downstream it became more dispersed and additional dye was added when necessary to increase the peak concentration to easily detectable levels.

Dye was added to the Reno effluent at 8:00 PM on one occasion and at 11:00 AM on the other. The DO concentrations observed in the river following each of these dye additions are plotted in Figures 17 and 18. The plots show entirely different findings which reflect the important effect of time of day on the DO observed.

These plots may be considered as showing the variation in DO which occurs in an incremental volume of river water as it moves downstream from the Reno outfall. The reactions which take place in this incremental volume of water which cause a change in its DO concentration, may be described as follows:

$$\frac{dC}{dt} = K_2 D_{(t)} - K_1 L_{(t)} + (P - R)_{(t)} \qquad (1)$$

where

C = dissolved oxygen concentration, ppm

D = oxygen deficit, ppm*

L = BOD concentration, ppm

(P - R) = the net effect of photosynthesis and respiration, ppm/day

K_1, K_2 = reaction rate constants of reaeration and deoxygenation, respectively, day^{-1}

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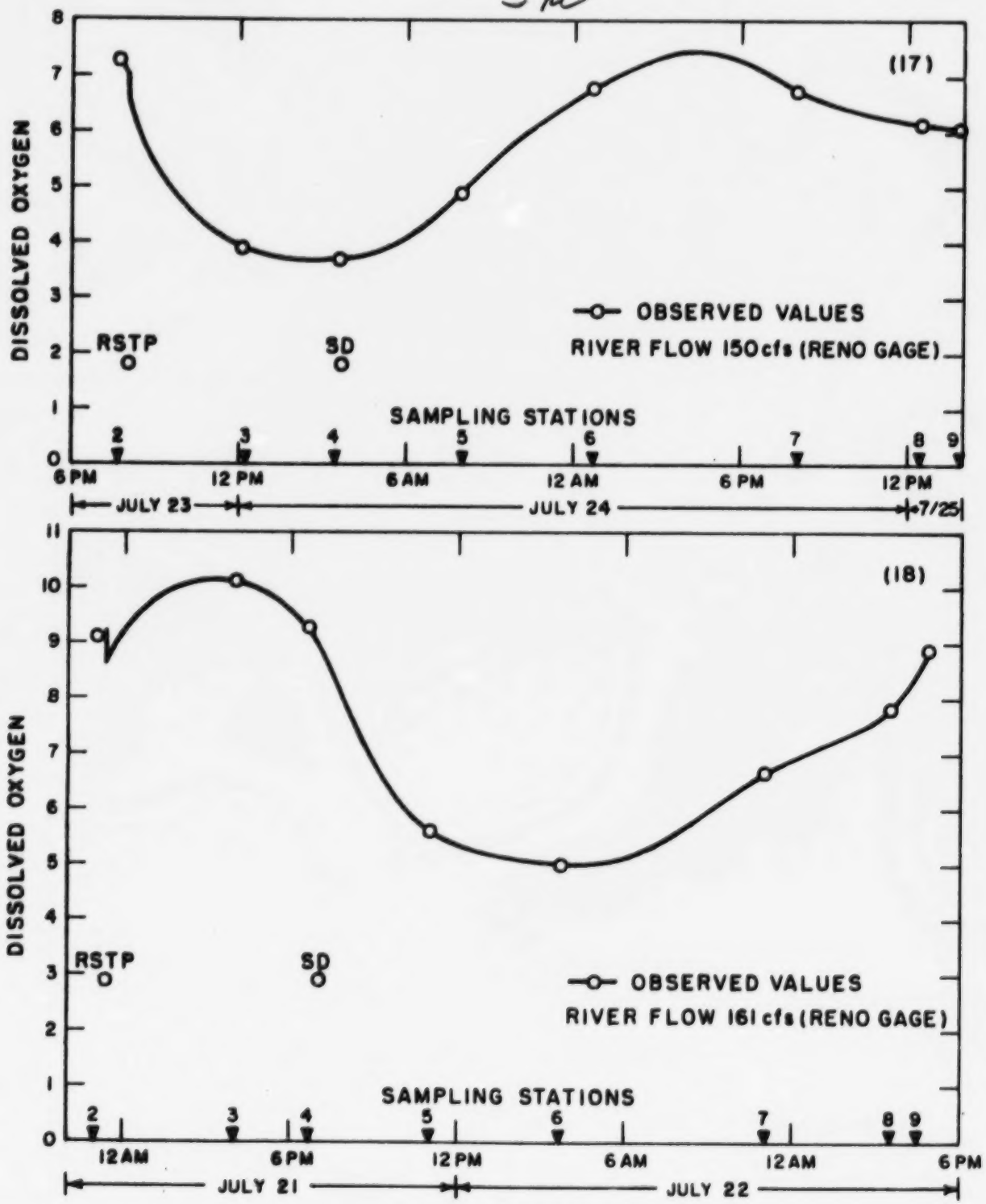
* Dissolved Oxygen saturation values were corrected for the Reno elevation of 4400 feet where at 20°C. the DO saturation level is 7.8 ppm, rather than 9.2 ppm as at sea level.

K_1 L, and D are known from stream observations. K_2 has been calculated from Velz's Standard Reoxygenation curve, using available knowledge of the stream's physical characteristics. Comparable values were obtained using the O'Connor formula. The rate of change of DO concentration, $\frac{dC}{dt}$, may be calculated in finite difference form from the curves in Figures 17 and 18. Thus, (P - R), which is an unknown function of time can be estimated by solving the above equation in finite difference form.

The necessary calculations to determine (P - R) for the nighttime curve (Figure 17) are shown in Table 9. Similar calculations were performed on the daytime curve (Figure 18) and the results of both of these sets of computations are summarized below. Only that portion of the oxygen curves extending eight hours below the Reno outfall to the critical location in the river near Station 4 was studied since detrimental effects on stream DO were greatest in this stretch of stream.

	Total Change in DO (ppm)	
	Night 8 PM - 4 AM	Day 11 AM - 7 PM
BOD Satisfaction (K_1L)	- 0.675	- 0.675
Reaeration (K_2D)	+ 2.96	- 2.12
Net biological effect (P - R)	- 5.19	+ 5.14

The above figures reveal the magnitude of the nighttime oxygen consumption in this stretch of stream by biological growths. In the eight-hour period before sunrise a net amount of 5.19 ppm of DO was removed from the river water by biological respiration. This is more than seven times the amount of oxygen required for satisfaction of the BOD. During the daylight hours from 11:00 AM to sunset, 5.14 ppm of DO were added to stream by photosynthetic oxygen production in excess of



D.O. CHANGE WITH FLOW DOWNSTEAM
TRUCKEE RIVER

FIGURES 17 & 18

Table 9

Computation of Net Photosynthesis-Respiration (P-R)

Time	DO (ppm)	$\frac{\Delta C}{\Delta t}$ (ppm/hr)	Temp. (°C)	DO at Sat. (ppm)	D Deficit (ppm)	K_2D (ppm/hr)	L (ppm)	K_1L (ppm/hr)	(P-R) (ppm/hr)
8:00 PM	6.60		22.	7.5	0.9		4.6		
		-1.40				0.172		0.09	-1.48
9:00 PM	5.20		21.5	7.6	2.4		4.5		
		-0.70				0.29		0.09	-0.90
10:00 PM	4.50		21.	7.7	3.2		4.4		
		-0.35				0.35		0.09	-0.61
11:00 PM	4.15		20.5	7.75	3.6		4.3		
		-0.20				0.385		0.085	-0.50
12:00 M	3.95		20.	7.8	3.85		4.2		
		-0.15			.	0.415	.	0.08	-0.49
1:00 AM	3.80		19.5	7.9	4.1		4.2		
		-0.05				0.435		0.08	-0.41
2:00 AM	3.75		19.	8.0	4.25		4.1		
		-0.05				0.450		0.08	-0.42
3:00 AM	3.7		18.	8.1	4.4		4.0		
		0.00				0.465		0.08	-0.38
4:00 AM	3.7		17.5	8.2	4.5	____	3.9	____	____
					Total (ppm)	2.96		0.675	-5.19

$K_1 = 0.485/day = 0.0202/hr.$

$K_2 = 2.5/day = 0.104/hr.$

$$(P\text{-}R) = \frac{\Delta C}{\Delta t} - K_2D + K_1L$$

respiration needs. However, since the oxygen content was always above saturation during these daylight hours, transfer of oxygen across the water-air interface by turbulent diffusion was from the stream to the atmosphere and 2.12 ppm of the excess oxygen were lost in this manner.

Thus, the most critical oxygen condition observed on the Truckee River during the survey, i.e., near Station 4 at sunrise, is affected primarily by the nighttime respiration of benthic and planktonic algae and other organisms in the stretch of stream immediately upstream. Although the algae produce oxygen in copious quantities during daylight hours, this oxygen is not available to the waters which, at night, follow the daylight supersaturated mass of water into the biologically active stretch of stream. The oxygen content of the water passing Station 2 at sunset is approximately at equilibrium with the atmosphere, or 100% saturated (see Figure 9) while that passing Station 4 at the same time is greater than 120% saturation. During the succeeding nighttime hours the more highly saturated waters having benefited from passage through the zone of active photosynthesis between Station 2 and Station 4 now are available at Station 5 and below to prevent an extreme depression in DO from taking place in the stream following entrance of the Sparks treatment plant effluent. The lower DO waters at Station 2 pass through the biologically active zone at night and must bear the burden of the continuous algal respiration that accompanies active daytime photosynthesis without the benefit of the excess oxygen which that photosynthetic activity produced. Thus, the location both in time and distance of the most critical DO conditions observed during the survey was determined not by

the organic waste load discharged to the river but rather by the stream's population of algae and other biological organisms.

Figure 9 shows that the only stretch of the river not experiencing supersaturated conditions was from just above Station 5 to just below Station 6, a distance of about ten river miles. These two stations also exhibited the lowest maximum DO values, 7.5 and 7.4 ppm, respectively, (Table 4) of any of the stream stations. The reason for this situation may be partially explained by considering the time of flow from Station 4 where a much greater diurnal variation exists. The time of flow from Station 4 to Station 6 was about ten hours at the July flows. Hence, the low DO waters at Station 4 just before sunrise or 4:00 AM would reach Station 6 at about 2:00 PM, near the time of peak photosynthetic activity in the stream. However, because the DO level in this parcel of water was so low at 4:00 AM, reaeration and photosynthetic oxygen production were unable to raise the DO above the 100% saturation level in the ten hours of flow time from Station 4 to Station 6. Similarly, the parcel of water in which the late afternoon DO peak at Station 4 occurred, was present at Station 6 just before sunrise and prevented the minimum DO at that point from reaching levels as low as those found at Stations 3 and 4. In effect, then, the diurnal DO curve at Station 4 (Figure 12) was out of phase with that at Station 6 by one-half a diurnal cycle and thereby caused a "dampening effect" on the diurnal DO curve at Station 6. Or, in other words, had there been little or no diurnal DO variation at Station 4, the range in DO found at Station 6 would probably have been greater, the maximum value being higher and the minimum lower.

This "dampening" effect, of course, affects all locations along the stream to some extent. The DO found at any station at a given time is affected by the past history of that parcel of water at upstream stations. It is very difficult, therefore, to isolate one small stretch of the stream for study without considering the diurnal variations of the length of stream at least one-half day's flow time above that point. Thus, if it were practical to eliminate photosynthetic and respiratory effects in the stream between Station 3 and Station 4, for example, the improvement in the stream by stabilizing DO levels there may be offset to some degree by adverse effects twelve hours downstream.

PREDICTION OF FUTURE CONDITIONS

The ability to predict the minimum dissolved oxygen content which might be expected at other waste loadings and stream flows is an important tool in planning for future pollution abatement requirements. In situations where the river DO is affected only by entering waste loads and stream reaeration capacity, such predictions can readily be made using the oxygen sag formula. Providing good information on waste and stream characteristics is available, this method will ordinarily provide reasonably good estimates which can be most useful for future planning. However, where oxygen levels are dependent primarily on stream photosynthesis and respiration as was the case on the Truckee River during July 1962, then the problem of making reasonably accurate future predictions becomes much more difficult, if not impossible. The major reason for this is due to the great variability in the behavior of the biological organisms responsible for photosynthesis and respiration in the stream. They are quite sensitive to changes in levels of the nutrient

elements, nitrogen and phosphorus, to changes in the availability of light, and to changes in temperature. The potential effectiveness of stream turbidity in limiting light penetration and thereby reducing photosynthetic activity may also be of importance. Many other factors as well undoubtedly influence the performance of algae and our knowledge of these is far from complete. The varability of stream DO due to the activities of photosynthetic organisms is illustrated in Figure 19. The rainstorm which occurred in the early morning of July 12 was observed to increase the turbidity of the river by a very noticeable degree, although analytical measurements were not actually made. The immediate effects on the diurnal variation in dissolved oxygen content were to significantly lower the maximum and raise the minimum daily values which were previously found at that station. The daily maximum and minimum values gradually returned to their former levels over the next five days. The cause of this great change in the diurnal DO pattern is primarily due to the increased stream flow which provided more dilution for the oxygen present, although the transient increase in stream turbidity may have exerted a minor influence.

In spite of the uncertainties involved, it is possible, by making certain assumptions regarding stream photosynthesis, to predict the effect of changes in stream flow on the minimum stream DO. Figure 20 shows such a relationship for the Truckee River at a point eight hours below the Reno outfall. This relationship was developed by assuming that the nighttime respiratory requirements of the stream's biological population in this stretch would remain at the level found during the survey and shown in Table 9. By the analysis shown in Table 9 it was found that

5.2 ppm of oxygen were consumed during the eight hours of darkness resulting in a minimum DO just prior to sunrise of 3.7 ppm. As shown in Table 5, this was the lowest value ever found at Station 4 and therefore the analysis in Table 9 can be considered as representative of the "worst" conditions encountered during the July survey. Although (P - R) varied through the eight hour time of passage of our incremental volume of water from 1.48 ppm/hr. to 0/38 ppm/hr., an average value of 0.65 ppm/hr. or 15.6 ppm/day was used as a constant for convenience in the succeeding calculations.

Continuing the estimating process in this vein, Equation (1) was modified to let the (P - R) remain constant. The differential form

$$\frac{dD}{dt} = K_1 L_{(t)} - K_2 D_{(t)} - (P-R) \qquad (2)$$

is solved by:

$$D_t = \frac{K_1 L_a}{K_2 - K_1}(e^{-K_1 t} - e^{-K_2 t}) + D_a e^{-K_2 t} - \frac{(P-R)}{K_2}(1-e^{-K_2 t}) \qquad (3)$$

By substituting as follows:

$K_1 = 0.485 \text{ days}^{-1}$

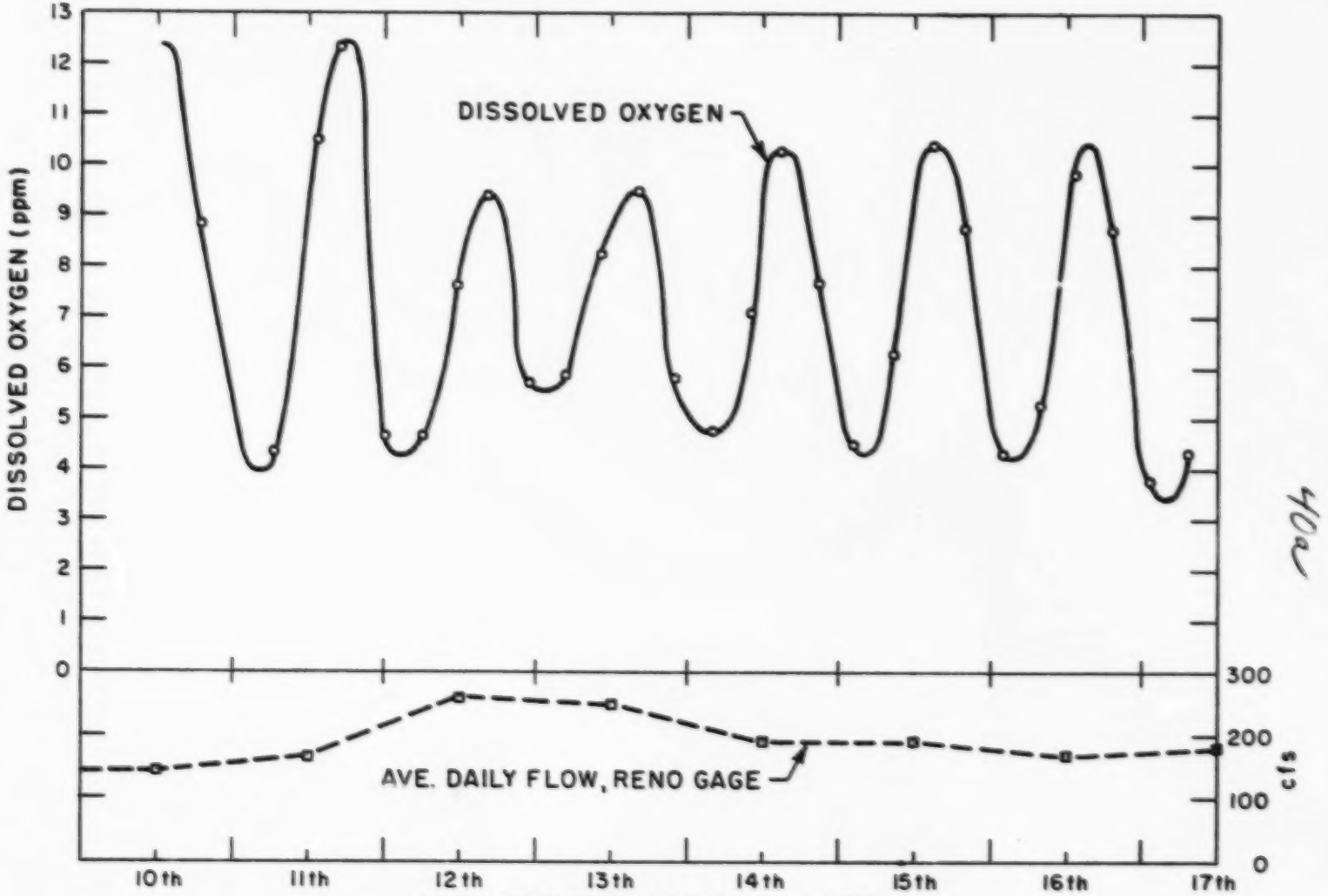
$K_2 = 2.5 \text{ days}^{-1}$

$D_a = 1.2$ ppm

$L = 4.6$ ppm

$(P-R) = -15.6$ ppm/day

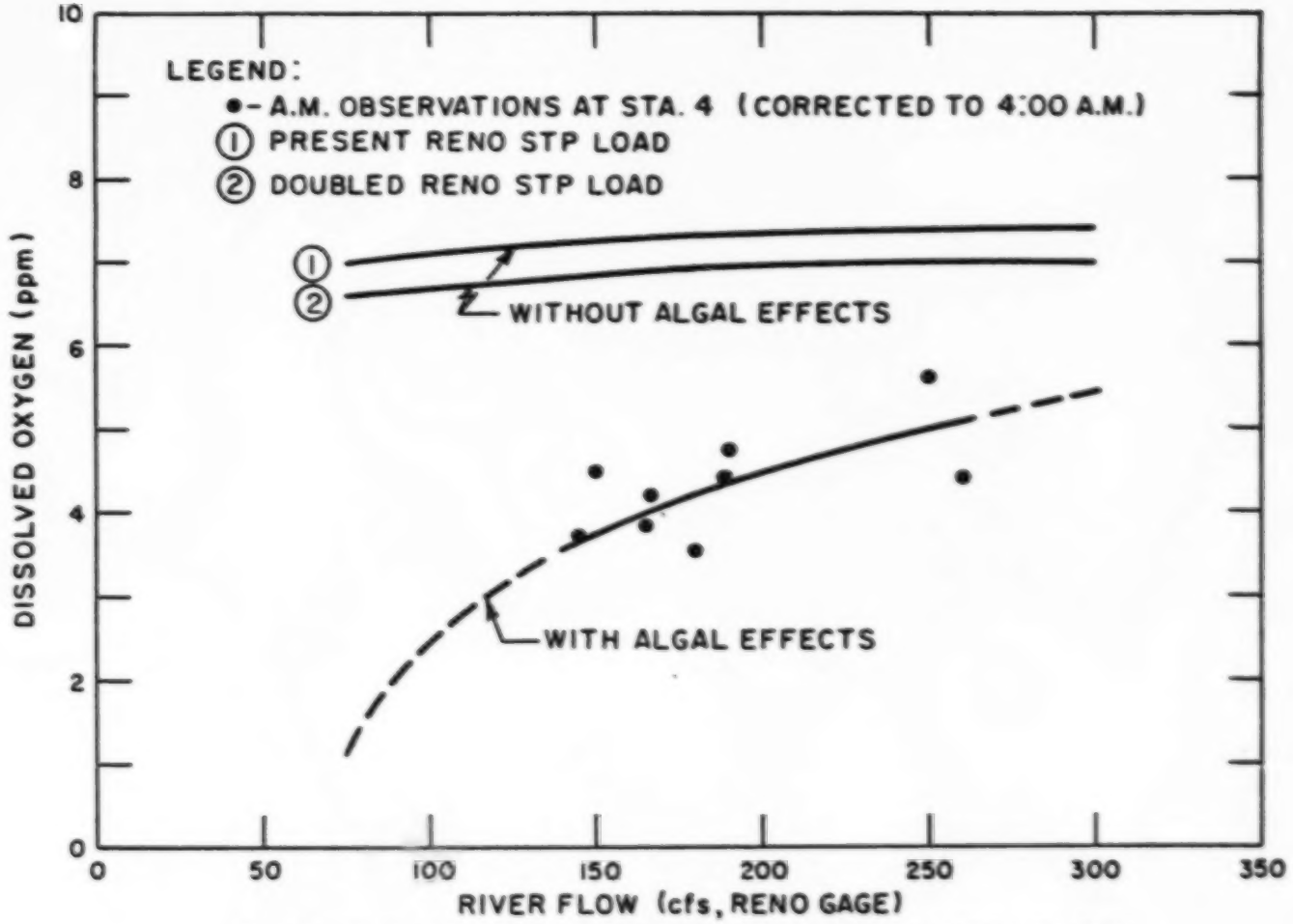
$t = 8$ hrs. $= 0.33$ days



DISSOLVED OXYGEN AND FLOW - STA.4

TRUCKEE RIVER

FIGURE 19



DAILY MINIMUM D.O. (AT SUNRISE) VS. RIVER FLOW
TRUCKEE RIVER

FIGURE 20

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the calculated deficit just before sunrise is found to be 4.5 ppm which, at the stream temperature of 17.5°C. observed at that time at Station 4, represents a DO of 3.7 ppm. This corresponds with the DO value actually observed. This indicates that potential errors associated with using the finite difference technique and in allowing (P - R) to remain constant at its average value rather than vary with time do not significantly affect the expected result.

In applying this technique to flows other than those occurring at the time the observations on Table 9 were made (150 cfs), it was assumed as a first approximation that the level of biological activity would remain unchanged. Thus, if oxygen were consumed by respiration in this stretch at a rate of 15.6 ppm/day at 150 cfs, a consumption rate of 31.2 ppm/day would occur at half that flow, or 75 cfs, if the total amount of oxygen consumed were to remain the same at both flows. Although this assumption is open to question when applied over a broad range of flows, at the flows observed during the survey, 145 to 260 cfs (Renc gage), this relationship fitted the observed DO data reasonably well. At flows outside this range (the dashed line on Figure 20) the critical DO levels predicted should be used cautiously. Although great confidence cannot be placed in the predicted DO values at flows less than 150 cfs, the trend exhibited by the dashed curve in Figure 20 toward much lower DO values at the lower flows is considered reliable and should be of value for planning purposes.

The constant DO levels which would theoretically exist in the stream in the absence of the biological activity have been estimated for the same

stream location and these are also shown in Figure 20. The upper curve was obtained by using the present waste load from the Reno STP while the lower curve results when this load is doubled. The three curves in Figure 20 illustrate two important conclusions regarding the oxygen characteristics of the Truckee River below Reno; (1) as much as 80 per cent of the daily maximum (pre-sunrise) oxygen deficiency at the critical location below Reno is apparently caused by the net oxygen uptake of the stream's biological life, and the remainder by the Reno waste effluent; (2) an increase in the waste loading added to the stream by as much as a factor of two would have slight effect on the daily minimum (pre-sunrise) stream DO as compared to the effects presently produced by biological activities.

The self-purification capacity of the Truckee is actually quite great, as would be expected of a shallow, swiftly-moving stream. In fact, the classical oxygen sag often found in streams below waste discharges would not be observed to any degree in the Truckee below Reno under present conditions of waste loading. Even at two or three times the present loading, in the absence of algal activity, the critical point in the river would exist near the point of discharge of the Reno effluent. At all downstream locations the stream DO would be higher than at the discharge point where the effluent with a DO of about 2.5 ppm mixes with the nearly saturated river water. Thus, in this case the minimum river DO would be controlled primarily by the DO deficiency in the discharged effluent and not by its organic load. However, the absence of algal activity, of course, cannot be assumed as we have done in this discussion unless the cause of this excessive activity is determined and means are available for controlling it.

In order to eliminate the low hourly DO values observed at Stations 3, 4, and 5 at sunrise, further investigation of the factors contributing to intense biological activity present just below Station 2 is warranted. Continuation of the present policy of preventing any flows from entering the river during its passage through the populated areas of the city is desirable to minimize the adverse oxygen condition in the Truckee River at Stations 3, 4, and 5.

If, in the future, the flow was decreased and/or the waste load increased in the Truckee River, environmental changes would take place with accompanying changes in aquatic life. Reduced flows would be accompanied by temperature increases. At the time of this survey the short term maximum temperatures at all stations were near or in excess of the upper lethal temperature determined for rainbow trout. It has been found that a temperature of 24°C. over a 24-hour period will produce 50 per cent mortality in rainbow trout.* An increase in the temperature of the water would decrease the amount of oxygen which the water holds, and at the same time increase the metabolic activity of aquatic organisms. Thus, an adverse effect attributable to temperature increase could eliminate a portion of the diversified benthic flora and fauna that existed during the survey.

The problems associated with reduced river flows could be intensified by increased sewage flows or a higher degree of waste treatment. These changes would result in the discharge of larger quantities of nutrients in

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* Black, E. C. "Upper Lethal Temperatures of Some British Columbia Freshwater Fishes." J. Fish. Res. Bd. Can., 10(4): 196-210. (1953)

readily available form, thereby increasing the potential for algal development. Thus, an accompanying increase in the diurnal fluctuation of dissolved oxygen would be expected. Much of the new diversified substrate might be eliminated to benthic inhabitants because of attached growth.

On the other hand, if settleable organic solids were increased stream changes such as substrate degradation, increased turbidity, and lowered dissolved oxygen would result. These changes would be reflected in the biota causing increases in tolerant benthic forms and decreases in sensitive forms.

The combined effects on aquatic life, because of increased waste loads and decreased flows, would be additive.

CONCLUSIONS AND RECOMMENDATIONS

1. A very significant diurnal cyclic variation in both temperature and dissolved oxygen content exists at all stations on the Truckee River. Maximum values will be found in late afternoon and miminum values just before sunrise. Future monitoring of stream quality should take this important factor into consideration.

2. Minimum observed DO concentrations were found at Stations 3, 4, and 5, one-half hour or more before sunrise. Most often the lowest value was found at Station 4. The most critical stream conditions, therefore, may routinely be observed at these stream flows by sampling at Station 4 at about one hour before sunrise.

3. The low DO conditions found at Station 4 are brought about by three factors which, in order of importance, are nighttime biological respiration,

addition of the low DO Reno STP effluent, and oxidation of the organic load added by the Reno effluent. The former is the most significant.

4. A zone of profuse growths of attached algae (Cladophora) exists between Station 2 and the entrance of the Reno effluent. The photosynthesis and respiration which take place in this stretch of the river cause large diurnal variations in dissolved oxygen over a stream length of approximately eight miles. The lowest dissolved oxygen values observed were caused by the nighttime respiration taking place in this zone. Further investigation of the factors contributing to this biological activity and of possibilities for its control is warranted.

5. The prediction of stream dissolved oxygen concentrations at loadings and flows other than those existing during the survey is made very difficult by the presence of these profuse algal growths. In the absence of such growths no significant depression of DO below that occurring just below the Reno outfall would be expected because of the high reaeration capacity of the Truckee River. However, because of the intense biological activity found during the survey, nearly complete exhaustion of dissolved oxygen may occur at summer flows below 75 cfs (Reno gage).

6. The efficiency of the Reno STP was found during the survey to be 85-90 per cent based on removal of first-stage or carbonaceous BOD. Because of the major influence of effluent nitrification the best and most consistent estimates of treatment efficiency at the Reno plant can be obtained by using modifications to the BOD test suggested by Sawyer* or by

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* Sawyer, C. W., and Bradney, L., "Modernization of the BOD Test for Determining the Efficiency of the Sewage Treatment Process." Sew. Works.Jour. 18:1113 (1946)

Ruchhoft.* The former involves destruction of the nitrifying bacteria while the latter calls for parallel nitrogen determinations.

7. The efficiency of the Sparks STP was found during the survey to be approximately 30 per cent, far below what should be expected from a plant of this type. Hydraulic overloading and short-circuiting appear to be the major factors responsible for this poor performance. Possibly as much as one third or more of the BOD discharged in the plant effluent may be in the form of settleable solids which are deposited in the effluent ditch prior to entering the river. The flushing of these solids during periods of high runoff could adversely affect the river.

8. All stream samples below the Reno effluent showed evidence of nitrification prior to the fifth day of incubation during the BOD test. From 40 to 60 per cent of the 5-day BOD of these stream samples, therefore, is due to the second or nitrogenous stage of the BOD reaction. Since the time of flow from Reno to Derby Dam is slightly over one day at commonly observed summer flows (200 cfs, Reno gage) the second stage oxygen demand is apparently not exerted to a significant degree in this stretch of stream.

9. The limited coliform analyses performed showed the effectiveness of chlorination at both treatment plants to be quite variable. As a result most stream samples showed coliform numbers in excess of levels ordinarily considered desirable.

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* Ruchhoft, C. C., Placak, O. R., Ettinger, M. B., "Correction of BOD Velocity Constants for Nitrification." Sew. Works Jour. 20:832 (1948)

10. Profuse attached algal growths below the city of Reno, but upstream from its sewage treatment plant outfall, were indicative of increased nutrient concentrations. Suppression of attached algal growths occurred between the Reno outfall and Derby Dam. Reduction in the number of kinds of benthic organisms also occurred in this stretch of river. The first station below the Reno Sewage Treatment Plant was somewhat biologically degraded. Organisms intolerant of organic pollution were present, but were reduced in number, and immature stoneflies and caddisflies were eliminated.

11. At reduced stream flows and/or increased waste loadings on the river, definite environmental changes that adversely affect the aquatic life would be expected.